AD-A050 082 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 17/7

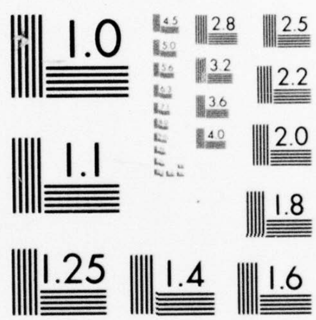
RADIO EGUIPMENT FOR AIR NAVIGATION,(U)

MAY 76 G P ASTAFYEV, V V GRACHEV, A S KULCHIY

UNCLASSIFIED FTD-ID(RS)T-0659-76 NL

1 OF 4

AD A050082



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FTD-ID(RS)T-0659-76

FOREIGN TECHNOLOGY DIVISION

RADIO EQUIPMENT FOR AIR NAVIGATION

by

G. P. Astaf'yev, V. V. Grachev, A. S. Kul'chiy

FTD- ID(RS)T-0659-76

(12) 359p.

UNEDITED MACHINE TRANSLATION

(11)

(14) FTD-ID(RS)T-0659-76 24 May 1976

FTD-76-C-000528

(6) RADIO EQUIPMENT FOR AIR NAVIGATION,

By: G. P. Astaf'yev, V. V. Grachev, A. S. Kul'chiy (10)

English pages: 353

(21) Unedited machine trans. of [redacted]

Source: Radiotekhnicheskiye Sredstva Vozdushnoy Navigatsii. Part 1. Radionavigatsionnyye Sistemy Osnovannyye na Izmerenii Vremeni Rasprostraneniya Radiovoln, Uchebnoye Posobiye, Leningrad, [redacted] pp1-161 1972.

Country of origin: USSR

This document is a machine aided translation.

Requester: 7602nd AINT/INXD

Approved for public release; distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

141600 Jrc

Table of Contents:

U. S. Board on Geographic Names Transliteration System....... ii

Russian and English Trigonometric Functions................. iii

Range-Finding Radio-Navigation Systems...................... 4

Bearing-Distance Radio-Navigation Systems, and.............. 116

Range-Difference Navigation Systems......................... 257

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ë in Russian, transliterate as yë or ë. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	*α*	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Υ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ *κ*	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

---

rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

MT/ST-76-659

jm87

SUBJECT CODE 1214

RADIO EQUIPMENT FOR AIR NAVIGATION.

G. P. Astaf'yev.

V. V. Grachev.

A. S. Kul'chiy.

Pages 1-161.

RADIC EQUIPMENT FOR AIR NAVIGATION.

Secticn cf the second.

The radic-navigation systems, based cn the measurement of the propagaticr time cf radic waves.

Textbcok.

Page 2.

In the second section of textbock "radic equipment for air navigaticn" are set forth the radic-navigaticn systems, based on the measurement cf the propagation time of radic waves. In chapter 1 are examined ranging RNS, in chapter 2 they are examined azimuth-ranging RNS and in chapter 3 - differential ranging RNS with continuous and pulse radio-wave emissicn.

The set forth material is the section cf the corresponding course, read the students at of the academy, and it can be useful for the kcmandnoletnogo compcsition of the civil aviation. Chapter 1 is written Kul'chiy a. s.; chapter 2 is Grachevym V. V.; chapter 3 - by Astaf'yevym g. p. Illustration 92. Table 1.

Page 3.

INTRODUCTICN.

In this secticn are examined the radic navigational aids whose work is based on the use of a dependence between the propagation time cf radio waves and the navigaticnal coordinate.

The propagation cf electrcmagnetic waves in free space occurs at constant velocity and rectilinearly; therefcre propagation time can be directly connected with the passed distance (or angular coordinate).

The radic-navigation systems, based on the measurement of the propagation time of radio waves, serve for determining the distances between two points of space or difference in the distances between this point of space and other two points. The first are called ranging systems or equipment/devices, and the second - differential ranging. The combined radio-navigation systems, which measure not only the distance, but also the direction, are called azimuth-ranging.

The measurement of the propagation time of radio waves can be conducted directly or indirectly. During indirect measurement are utilized continuous electromagnetic signals and it is measured the value of phase or frequency which are connected in the course of time radiowave propagation, while with direct - pulse electromagnetic signals; in this case the communication/connection between the navigational coordinate and the parameters of radio wave at any point of space (by time t or by phase ϕ) it takes the form:

$$R = ct \quad \overset{(1)}{\text{и}} \quad R = \frac{c}{\omega}\varphi,$$

(1)
and

where c is velocity of propagation of radic waves; ω - angular frequency.

Page 4.

In accordance with this, are distinguished time/temporary, phase and frequency radio navigational devices and the systems.

In this textbook are examined the ranging radio-navigation systems of time/temporary and phase types, time/temporary type azimuth-ranging systems and the differential ranging radio-navigation systems of time/temporary, phase and fazo-time/temporary types. All these systems find wide application in the radio navigation of flight vehicles.

Page 5.

Chapter 1.

RANGE-FINDING
~~RANGING~~ RADIO-NAVIGATION SYSTEMS.

§ 1.1. Effect of the conditions of radiowave propagation on the operation of radio-navigation systems.

The accuracy of work of radio-navigation systems depends on the conditions of radiowave propagation. Under the ideal conditions of propagation the errors would be minimum; by such obrazon, if the velocity of propagation of radio waves was constant, and the direction of wave front by constant/invariable, then phase, frequency and time/temporary radio-navigation systems would have the minimum errors. Since in actuality occur changes in the velocity of propagation of radio waves, appear the measuring errors of the navigational parameters - systematic and random; the first almost completely can be excluded from the results of the measurements by calibration, the

second can be taken into account only on the average, they increase the fluctuation error of the navigational parameter. Therefore in a number of cases it is necessary to consider the effect of the conditions of radiowave propagation on a change in velocity and direction of the arrival of radio waves.

The velocity of propagation of radio waves and the trajectory of propagation depend on the following factors: change in the parameters of lower and upper air (troposphere and the ionospheres); the electrical properties of the underlying surface; area relief.

The velocity of propagation of radio waves in the atmosphere depends on temperature, pressure and humidity. Its value is determined by the relationship:

$$c = \frac{c_0}{\sqrt{\varepsilon}} = \frac{c_0}{n}, \tag{1.1}$$

where c_0 is velocity of propagation of radio waves in vacuum; ε - composite dielectric relative constant; n is a refractive index of the atmosphere.

Page 6.

For the Earth's atmosphere is characteristic the dependence of temperature, humidity and pressure from height/altitude. On the basis of the large amount of measurements for the wide interval of time, a change in the refractive index with height/altitude it is possible to

approximate by the exponential:

$$(1.2).\quad (n-1)\,10^{-6} = 313e^{-0{,}136H}.$$

Refractive index n decreases with height/altitude, and for a standard atmosphere lapse will be

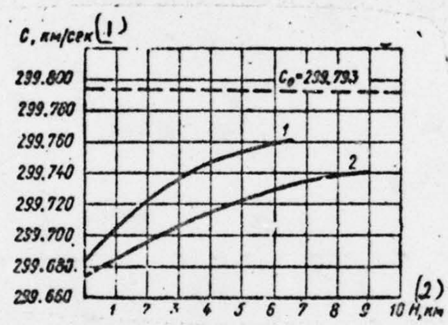
$$g_H = \frac{dn}{dH} = -4 \cdot 10^{-8}\ 1/м.$$

A relative change in the refractive index n in season for average/mean fluctuations of temperature, humidity and pressure is 10^{-4}. The velocity of radiowave propagation in vacuum, according to the last/latter data, is determined with the relative error, approximately equal to 10^{-6}. Consequently, with the complete account of changes in the velocity of propagation of the radio waves, caused by the instantaneous values of the atmospheric parameters, it is not possible to obtain the relative measuring error of distance less than 10^{-6}. If the relative measuring error of time interval is more than 10^{-3}, then the introduction of correction for a change in the velocity of the rasprostran of yeniya becomes unnecessary; with a measuring error less than 10^{-3}, the introduction of correction can raise the accuracy of the determination of navigational coordinate. The account of corrections for a change in the velocity of propagation it is expedient to produce in the devices of high accuracy (phase); if the

measurement of time interval is made through leading impulse front, then to consider changes in the velocity of propagation not is compulsory.

Fig. 1.1. Dependence of the velocity of propagation of radio waves on the height/altitude: 1 - empirical curve; 2 - calculated curve.

Key: (1) km/s. (2) N, km.



The curve/graph, which characterizes the dependence of the velccity cf propagation of radic waves on height/altitude, is shown im Fig. 1.1.

A change in the electrical parameters cf scil affects the velocity cf propagation of radic waves in sтch a case, when the dividing line of sections with the different parameters is lccated near the transmitting or receiving antennas.

Page 7.

In this case the replacement of the electrical parameters of soil leads to a change in the process of the establishment of "phase" velccity.

To analogous phenomena it leads the heterogeneity of relief about receiving antenna.

During the propagation of pulse signals in the ionosphere the "group" velccity * will depend cn the state cf the ionized layer. [[FOOTNOTE * concepts to "phase" and "group" velccity are introduced for the media, dielectric constant of which and velocity of propagation depend on frequency. This is related, in particular, to ionized gas. In such media the velocity cf propagation of radio wave determines the speed of the advance of the phase of wave (phase velccity). The group velocity characterizes the speed of the advance of energy. ENDFOOTNOTE]]. The reascn for this entails the fact that the dielectric constant of the ionized medium, which determines

velccity cf propagation of radio waves, depends on ionization density and the latter is changed by height cf layer and in time.

The conditions of radiowave propagation affect the extent of radio path and the values of the angles hearth by which wave comes into the pcint/item of reception/procedure.

During the propagation of ground waves the route of radio beam passes above the earth's surface of different form, i.e., along route occurs the replacement of the parameters of the underlying soil. Wil occur a change in the relief. All this will cause a change in the phase velccity; along wave front phase velccity is changed tc different degree and therefore it will cccur a change in the directic of radiowave propagation. Most significant these changes will be at coastal feature.

Refraction (curve) in the troposphere leads to a change in the direction cf the radiowave propagation and extent of radiotrassy. Usually in the trcposphere dielectric constant falls with an increase in altitude, which leads to a decrease in the refractive index n; in this case the trajectcry becomes curvilinear with the convexity, turned upward. The length of route exceeds geometrically the shortest distance between the transmitting and receiving point/items, and the angles of arrival of wave will differ from the angles hearth as which passes gecmetrically the shortest route.

The reflection cf radio waves from the ionosphere also leads to change in length and orientation of radiotrassy. In the case of phas radic-navigation systems the phase of the wave reflected will differ from the phase of the wave, which is propagated cn arc of the great

circle.

Page 8.

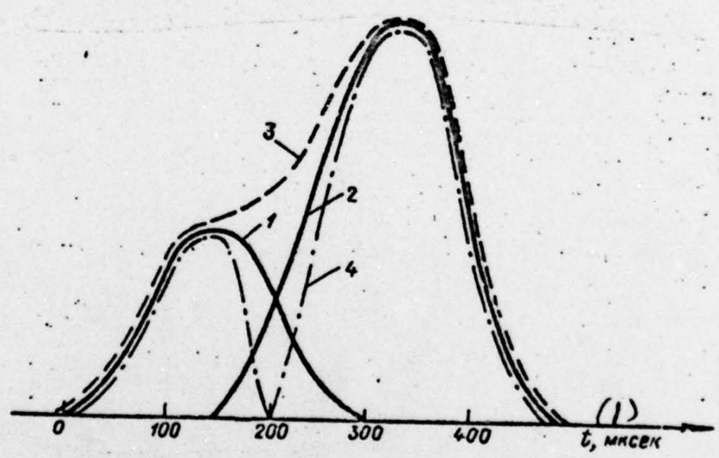
When using the average/mean and long waves when at the point of reception/procedure is observed the interference of surface and sky waves, will change the phase of the resulting wave. In the case of pulse (time/temporary) devices an increase in the length of radiotrassy leads to the time lag of the radio wave reflected.

During the transmission of the pulse signals through the ionosphere appears the distortion of the shape of pulse. This is connected with the fact that the phase velocity depends on the frequency of radio waves; therefore the different frequency components of the spectrum of pulse signal obtain different increments in the phase, and the new phase relationships of spectral components lead to the deliquescence of pulse signal.

The distortions of pulse signal develop themselves also, when pulse duration is greater than a time difference the propagation of different waves, for example, with the simultaneous reception/procedure of surface and sky waves in long-wave and medium-wave ranges. Similar distortions were observed during the operation of differential ranging system (frequency f = 180 kHz; pulse duration τ = 300 μs). The time/temporary relationships, which are obtained in this case, are shown in Fig. 1.2. Depending on the phase relationships of both momentum/impulse/pulses changes the form resulting that which go around.

Fig. 1.2. A change in the form of pulse signal in the presence of the interference of the surface and sky waves: 1. and 2. the pulse signals of surface and sky waves; 3 - resulting going around, if both momentum/impulse/pulses are cophasal in high frequency; 4. the same, if momentum/impulse/pulses are antiphase.

Key: (1) t, μs.



Page 9.

§ 1.2. Principles of RADIODAL'NOMETRII and accuracy.

In ranging radio-navigation systems (RNS) the carrier of navigatical data is time t = t (x). The measurement of time and construction on this principle RNS is possible because of the constancy of the velocity of propagation of radio waves and straightness in homogeneous medium.

By prolonged experimental studies in the different countries by different methods established/installed the following value of the velocity of propagation of radio waves in free space (vacuum):

$$c = 299693 \pm 10 \text{ км/сек}^{(1)}$$

(1) km/s.

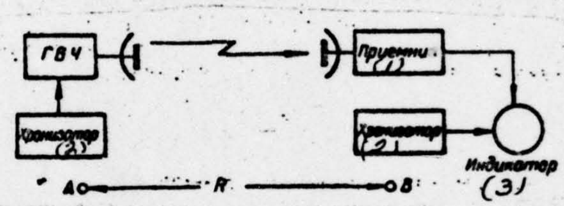
In air the velocity of propagation of radio waves decreases and depends on the density of air medium about the poverkhnostiZemli:

$$c = 299693 \pm 10 \text{ км/сек}^{(1)}$$

(1) km/s.

Fig. 1.3. Simplified block diagram of radio distance gauge with the independent timers: GVC - high-frequency cscillator.

Key: (1) receiver. (2) timer. (3) indicatcr.



If from point A (Fig. 1.3) to emit electromagnetic energy, then it, being propagated in the form of radio wave at constant velocity c in the direction R, will arrive to point B with time lag for a period t_R.
After measuring the propagation time of radio wave from point A into point B and by knowing velocity of propagation c, it is possible to determine the distance:

(1.3). $R = c \cdot t_R$.

During the measurement of distances of the reflecting object, the transmitter and the receiver of radio distance gauge are usually are territorial combined (Fig. 1.4).

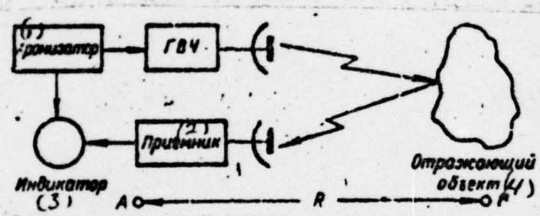
Page 10.

In this case the transit time of radio waves from transmitter to the reflecting object and vice versa to receiver t_R and the distance between them R are connected by the dependence:

(1.4). $R = \frac{c \cdot t_R}{2}$.

Fig. 1.4. Simplified block diagram of radio distance gauge with combined transmitter and receiver (and by timer).

Key: (1) timer. (2) receiver. (3) indicator. (4) the reflecting object.



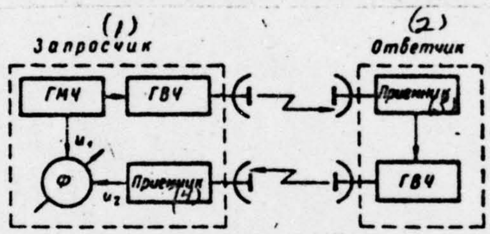
Sometimes for an increase in the range of radio distance gauge for the objective it is establish/installed responder (Fig. 1.5); in this case the transit time of radio waves from transmitter to responder and vice versa to receiver and the distance between the point/item of measurement and the responder are connected by the relationship:

$$R=\frac{c(t_R-t_0)}{2}, \quad (1.5)$$

where t_0 is a signal delay in responder's circuits.

Fig. 1.5. Simplified block diagram of radio distance gauge with a relay (of type "demand - answer/response").

Key: (1) interrogator. (2) responder. (3) receiver. (4) receiver.



Since the real medium is not strictly uniform, also the velocity of propagation of radio waves will not be constant in all path of propagation, but trajectory by strictly rectilinear. However, the given relationships will be valid also for a real medium, if we by the velocity of propagation of radio waves c understand the average value in which are taken into account the averaged actions of medium and the length of route [4].

Page 11.

With comparatively small distances (hundred of kilometers) the propagation time of radio waves, which underlies measurement, proves to be very low value. For example if $R = 300$ km, and $c = 3 \cdot 10^5$ km/s, then $t_R = 1000$ μs.

Therefore appeared the need for the creation of devices for the precision measurement of small time intervals - timers. Their application/use made it possible to develop radio engineering systems for the precision measurement of distances.

Accuracy of radiodal'nometrii.

The error in ranging appears, if the taken average value of the velocity of propagation of radio waves differs from the true or time interval is measured with error. From relationships (1.3-1.5) it is possible to find the error in determination of distance, after taking

the particular translatory derivatives of radiowave propagation and in terms of time. In this case we will obtain:

$$dR = \frac{\partial R}{\partial c}dc + \frac{\partial R}{\partial t_R}dt_R.$$

Replacing differentials by the finite increments and taking into account that

$$\frac{\partial R}{\partial c} = t_R = \frac{R}{c}, \quad \text{a} \quad \frac{\partial R}{\partial t_R} = c,$$

we will obtain

$$\Delta R = \frac{R}{c}\Delta c + c\cdot\Delta t_R, \tag{1.6}$$

where ΔR - dla'nomernaya error; Δc - the error of the average value of the velocity of propagation of radio waves; Δt_R — the error of time interval t_R.

Analogously from relationship (1.4) for a range finder with the combined timer we will obtain:

$$\Delta R = \frac{R}{c}\Delta c + \frac{c\cdot\Delta t_R}{2}. \tag{1.7}$$

The expression of ranging error is correct for a range finder with responder, if is known the precise value t_0.

From (1.6) and (1.7) it is evident that the ranging error consists of two terms. First term is determined by the authenticity of the dependence of the average velocity of propagation of radio waves on different factors and by the correctness of the account of these factors.

Page 12.

Second term depends on the instrument/tool accuracy of radio distance gauge, i.e., on the method of range finding, relation signal - interference, the frequency stability of the supporting/reference oscillations and other factors. Even with the high technical perfection of the range finder when $\Delta t_R = 0$, the ranging error

$$\Delta R = \frac{R}{c} \Delta c,$$

whence

$$\frac{\Delta R}{R} = \frac{\Delta c}{c}. \quad (1.8).$$

From (1.8) it follows that the relative ranging error is equal to the relative error in determination of the velocity of propagation of

radio waves. This value of error is maximum for the taken value of the accuracy of the determination of velocity. Let us find the value of the error of range finder for the different values of an error of measurement of time and velocity.

Let $R = 300$ km; $c = 3 \cdot 10^5$ km/s; $t_R = 10^{-3}$ s; $\Delta c = 10$ km/s; $\Delta t_R = 0{,}1 \cdot 10^{-6}$ s, then from (1.6) we obtain $\Delta R = 40$ m.

If $\Delta c = 1$ km/s, and $\Delta t_R = 0{,}01 \cdot 10^{-6}$ s, then $\Delta R = 4$ m.

The square mean of the error of range-finder σ_R can be determined from the formula:

$$\sigma_R = \sqrt{\sigma_c^2 + \sigma_{t_1}^2}$$

where σ_c — is a root-mean-square measuring error of distance due to error in velocity; σ_t — the root-mean-square measuring error of time. For the examined example $\sigma_c = 10$ m, and $\sigma_t = 30$ m, then $\sigma_R \approx 32$ m.

As can be seen from these examples, the radio engineering methods of the measurement of distances possess great possibilities in the sense of an increase in the accuracy of the measurement of distances.

The radio distance gauges, executed by diagram (see Fig. 1.3), are called range finders with independent timers, by diagrams (see Fig. 1.4) and (see Fig. 1.5) with the combined timers.

Radio distance gauges with independent timers are applied in radio navigation when it is expedient to have the one-sided communication line of communication. Radio distance gauges with the combined timers are applied in radar and in radio navigation.

Page 13.

For the measurement of time intervals and, therefore, distances are applied time/temporary, phase-difference and frequency response methods. In this textbook will be examined, mainly, the first two method.

§ 1.3. Operating principle of pulse ranging systems with the relay retort of signals.

Pulse ranging system with the relay retort of signals (see Fig. 1.5) is the totality of two devices - interrogator and responder, establish/installed in the opposite points of the communication line of communication. Interrogator is establish/installed at the measuring point of distance (usually on aircraft), and responder it is establish/installed at the point to which is conducted the measurement of distance (at the end the runways, for example).

The interrogator of range finder develops the coded inquiring signal, emitted at the frequency of demand f_3 and which is the set of several high-frequency pulses, distant from each other to the determined (code) time intervals. Inquiring signals with the aid of antenna are emitted into space. On the earth/ground these signals it accepts the relay of range finder (responder). After their amplification in receptor is form/shaped the response signal, which with the aid of the transmitter of relay and antenna is emitted into

space at the frequency of answer/response f_c, which differs from interrogation frequency. Response signal also is the determined code.

Interrogator picks up signal of responder; after amplification and conversions in receptor response signal enters measuring circuit where is determined the time interval between inquiring and response pulse signals, and then it is determined distance.

The time lag of response signal relative to inquiring is determined by the propagation time of radio waves from interrogator to responder and vice versa, and also by the supplementary signal delay t_0, connected with the formation of response signal in responder and processing response signal in interrogator. Value t_0 does not depend on distance and is considered during measurement. The communication/connection between time lag and the measured distance is determined by formula (1.5).

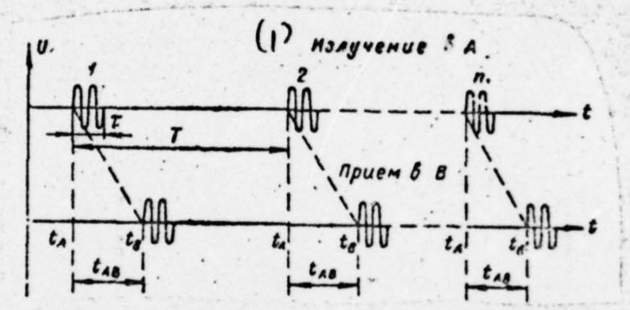
In pulse ranging systems as inquiring and response signals are utilized pulse high-frequency oscillations.

Page 14.

The measurement of propagation time substantially is lightened during pulse radio-wave emission. Figure 1.6 shows the time diagrams of processes with the pulse method of the measurements of time intervals.

Fig. 1.6. Time diagrams.

Key: (1) emissicn/radiation in A. (2) reception/procedure in B.



From diagram it follows that the time lag of response signal is defined as difference between time of reception/procedure (t_B) and of emission/radiation (t_A) the electromagnetic energy:

$$t_{AB} = (t_B + nT) - (t_A + nT) = t_B - t_A;$$
$$t_{AB} = t_B - t_A.$$

For determining the propagation time of radio waves it is necessary to accurately know the torque/moment of their emission/radiation t_A being the zero time reference. For this purpose at the point of reception/procedure (at measuring point) it is necessary to store the zero time reference (torque/moment of emission/radiation $t_A + nT$).

For storage of time serve the timers (synchronizers), based on the use of high-stability oscillations, developed as crystal or molecular oscillator.

The relative stability of crystal oscillators can be led at present to the value:

(1.9). $$\frac{\Delta t}{T} = 10^{-8}.$$

The care/drift of such "hours" $\Delta t = 10^{-8} T$.

where T is a duration of storage of time for determining reading.

For days (T = 86.400 s) care/drift will be equal to:

$$\Delta t = 10^{-8} \cdot 86400 = 10^{-3} \text{ сек.}^{(1)}$$

(1) s.

This corresponds to care/drift on 1 s for three years.

Page 15.

The relative stability of molecular generators is characterized by the relaticn

(1.10). $$\frac{\Delta t}{T} = 10^{-10}.$$

Molecular generators have a harcling the days:

$$\Delta t = 10^{-10} \cdot T = 10^{-5} \text{ сек.}^{(1)}$$

(1) s.

This corresponds to care/drift on 1 s in 300 years. However, already through days because of the measuring errors of time is accumulated the measuring error of distance, equal to

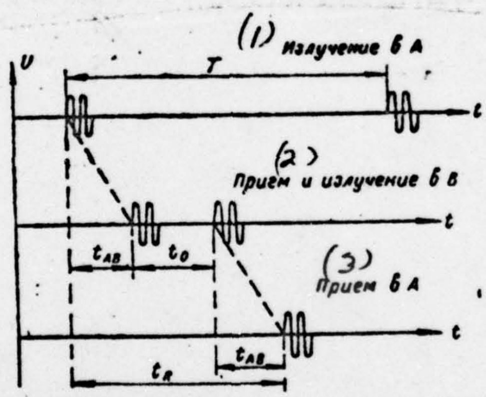
$$\Delta R = c \cdot \Delta t = 3 \cdot 10^{5} \cdot 10^{-5} = 3 \text{ км.}^{(1)}$$

(1) km.

For an increase in the accuracy of the measurement of distances it is necessary to shorten the storage time reference point. This is reached in ranging systems with the relay retort of signals (Fig. 1.7).

Fig. 1.7. The time diagrams of pulse processes in ranging RNS with relay retort.

Key: (1) emission/radiation in A. (2) reception/procedure and emission/radiation in B. (3) reception/procedure in A.



The total time between inquiring and response signals is determined by the expression, analogous (1.5):

$$t_R = 2t_{AB} + t_0;\quad t_{AB} = \frac{R_{AB}}{c} = \frac{1}{2}(t_R - t_0);$$
$$R_{AB} = \frac{c(t_R - t_0)}{2}.$$

Consequently, the error of range finder with the relay retcrt of signal can be determined from expression (1.7).

Eage 16.

The communication/connection between the root-mean-square measuring errors of distance and time interval of the time lag of reciprocal momentum/impulse/pulse relative to inquiring can be found from this expression, i.e.

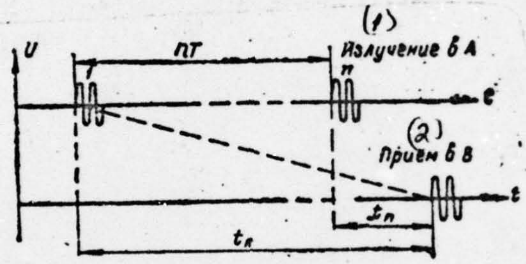
(1.11). $\sigma_R = \frac{c}{2}\sigma_t.$

In these systems substantially is simplified the storage of the zero time reference. Instead of several hours (when using in aviation) or several days (when using in fleet), as it takes place in range finders with separate timers (see Fig. 1.3), it is required to

store reference point during fractions of a second from the torque/moment of emission/radiation to the torque/moment of the reception of pulse signal (for a period of time of radiowave propagation $t=\frac{2R_{AB}}{c}$).

Fig. 1.8. Ambiguity of reading in sampled-data systems.

Key: (1) emission/radiation in A. (2) reception in B.



In pulse ranging systems with the relay retort of signals can arise the ambiguity of reading. This possibility escape/ensues of the periodicity of processes in impulse circuits. Time interval is measured between reciprocal momentum/impulse/pulse and first the which precedes it interrogation pulse (Fig. 1.8). The measured time interval will be equal to:

$$t_R = t_x + nT,$$

where T is equal the repetition period of interrogation pulses; n is a number of whole repetition periods of the interrogation pulses, which are placed for the propagation time of momentum/impulse/pulses from inquiring station to the reciprocal and vice versa.

Page 17.

Of the last/latter equality it follows that in the general case the reading of range is ambiguous, since is unknown the number of whole periods n. The condition of the unequivocal reading of range is the inequality:

$$0 \leqslant t_{R_{\text{макс}}} \leqslant T. \quad (1.12)$$

or

$$T \geqslant \frac{2R_{макс}}{c}, \quad F \leqslant \frac{c}{2R_{макс}}.$$

As an example let us find the extreme value of the repetition frequency of the interrogation pulses (and period) of the ranging system, which has the maximum range 300 km by which is still possible the unequivocal determination of distance. From expression (1.12) it follows that

$$F = \frac{c}{2R_{макс}} = \frac{3 \cdot 10^5 \text{ км/сек}^{(1)}}{2300 \text{ км}^{(2)}} = 500 \text{ гц}^{(3)};$$

$$T = \frac{1}{F} = 2000 \text{ мксек.}^{(4)}$$

Key: (1) km/s. (2) km. (3) Hz. (4) μs.

The real repetition frequency of interrogation pulses is selected less than maximum.

The duration of interrogation pulses usually is selected into hundreds and thousand of times less than the repetition period of momentum/impulse/pulses it composes value from the tenths of microsecond to several microseconds.

Ranging radio-navigation systems with the relay retort of signals can be several forms:

- interrogator is placed on aircraft, responder on the earth/ground;

- interrogator it is placed on the earth/ground, responder on aircraft;

it is placed by the combined ranging RNS, which have interrogator and responder both on the earth/ground and on aircraft.

In the first case the navigational information about range is obtained directly aboard the aircraft and is utilized for navigational target/purposes.

In the second case the navigational information about range is obtained on the earth/ground and transmits to edge for use in navigational target/purposes, or it is utilized on the earth/ground in the interests of the flight control (induction, air traffic controls).

In the third - given on range are obtained both on the earth/ground and on aircraft.

In each form of systems are inherent their special feature/peculiarities and properties, in particular, capacity. For example the capacity of ranging system with interrogator on aircraft is determined by the possibilities of ground-based responder, his charging.

Page 18.

With the frequency of interrogation pulses F and number n of the requesting aircraft the amount of reciprocal momentum/impulse/pulses will be:

$$N=n\cdot F.$$

The maximum value $n_{макс}$ is restricted to transmitter of responder, to his average power. Usually $n_{макс}=20-100$ aircraft it is simultaneous. Each responder is designed for the determined charging. However, in practice to responde. can enter larger the number of inquiring signals, than it is able to re-emit. In connection with this in responder must be provided the measures, which shield him from overloading.

§ 1.4. Methods of measurement of time intervals in pulse ranging systems.

The very important stage of work of pulse ranging systems is the measurement of the very small intervals of time, which are of the order of milliseconds. Let us pause at the methods of measurement of such time intervals.

At the principle of all methods of measurement lie/rests the comparison of the measured time interval with some standard constant or alternating/variable intervals of time or the comparison of the measured interval with the appropriate interval of any slowly elapsing process.

During the measurement of time intervals are applied the direct methods and compensation methods. Direct methods are based on the direct measurement of time interval. Compensation methods are based on the substitution of the measured interval by other, artificially

introduced, and on value determination of the latter.

Measurement of time interval with the aid of electron-beam indicator.

This method finds wide application in radar technology. Its essence consists of the following. The transmitter of inquiring station simultaneously with the consumption/production/generation of inquiring signal starts square-wave generator, and the latter, in turn, the voltage generator of scanning/sweep (Fig. 1.9). Sweep trace on screen CRT [ЭЛТ- cathode-ray tube] - time axis is formed during the deflection of the ray/beam of the tube with the from left to right saw-tooth sweep oscillator voltage. Under the effect of this voltage the electron beam moves over screen with certain constant velocity V_p. On completion of the foreward stroke of scanning/sweep the voltage on deflector plates decreases and ray/beam returns to starting position. Back stroke must end to the arrival of the following inquiring (starting/launching) momentum/impulse/pulse.

Page 19.

For a period flyback of tube rasitsya by large negative displacement on its grid. For a period of foreward stroke the tube is open/disclosed by the momentum/impulse/pulse of illumination.

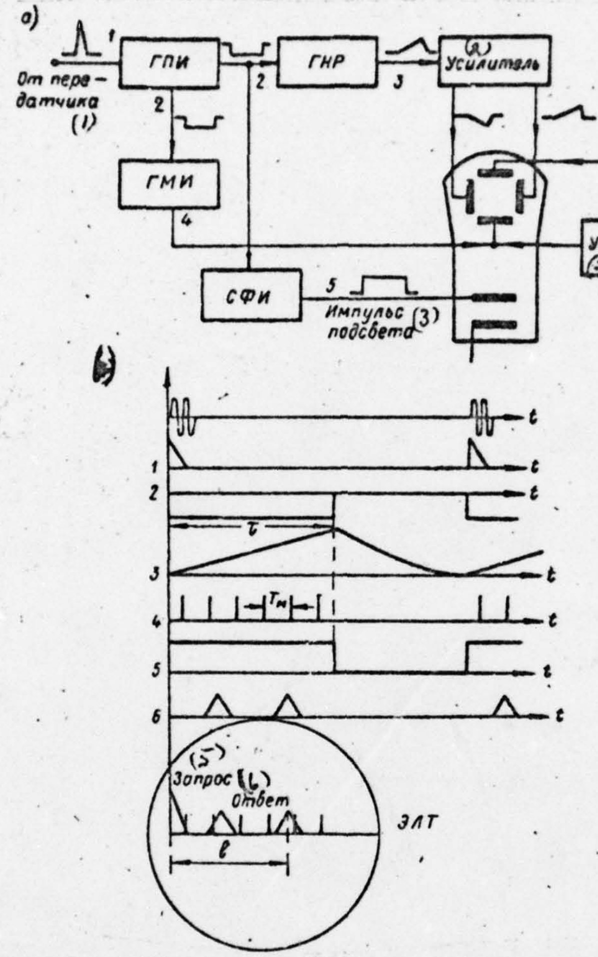


Fig. 1.9. Measurement of time interval with the aid of Elie: a) the block diagram of the indicator: GPI - the square-wave generator, GNR - the voltage generator of scanning/sweep, GMI - the range-marker oscillation, SFI - the pulse-shaping circuit of illumination; b) time diagrams.

Key: (1) from transmitter. (2) amplifier. (3) the momentum/impulse/pulse of illumination. (4) from priyemmika. (5) inward. (6) answer/response.

MT/ST-76-659

jm88

SUBJFCT CODE E214

Page 20.

Signal from the output/yield of receiver after its amplification to the necessary level with video amplifier is supplied to the vertical deflectors of tube, causing the appearance of a momentum/impulse/pulse of answer/response. Thus, on screen CRT [ЭЛТ - cathode-ray tube] will be visible the momentum/impulse/pulses of zapcsa and answer/response. Since the beginning of scanning/sweep coincides with the beginning of interrogation pulse, the glowing spot on tube face will be moved in horizontal direction synchronous with the motion of interrogation pulse in space, but at considerably lower speed. The distance up to which will be displaced the spot up to the torque/moment of the arrival of the echo pulse, depends on distance of the reflecting object. At constant scanning speed this distance:

$$l = V_p \cdot t_R = \frac{2V_p}{c} R = M \cdot R, \tag{1.13}$$

where V_p is a scanning speed; M - the scale of linear

scanning/sweep.

The measurement of the delay time in the reciprocal momentum/impulse/pulse can be realized with the aid of "mechanical" or "electrical" range scale directly on tube face. If thickness risk on the scale does not exceed the size/dimension of the momentum/impulse/pulse of answer/response, then the accuracy of reading is determined by the distance between two adjacent divisions. Operator's eye badly/poorly distinguishes parts within limits 1 mm. This distance usually is selected between two adjacent markers. The size/dimension of the entire scale for on-board indicators, as a rule, does not exceed 100 mm. Therefore operator's error will compose approximately the half of the scale graduation, i.e., in this case of 0.5c/c of length of the scale.

The mechanical scales give parallaxes. The electrical scales are free from these errors; however, the instability of the oscillator frequency of electronic markers can cause a change in the scale value.

They are commonly used several sub-ranges of range, then at short distances the absolute error of ranging somewhat descends.

The size/dimension of the scale on scope can be increased by the application/use of the circular sweep which is formed during the supplying to the horizontal and vertical deflector plates of the tube of the sine voltages, out of phase by 90°. The speed of the motion of spot along circumference will be constant, i.e., scanning/sweep linear in time, under the condition of the strictly sinusoidal form of sweep voltage, the phase shift, equal accurately 90° and with

$$h_x \cdot U_{m_x} = h_y \cdot U_{m_y}.$$

where h_x and h_y - the sensitivity of tube on X and Y to plates; U_{m_x} and U_{m_y} — the amplitude of the stresses, applied to plates.

Page 21.

Electron beam passes one circumference during the voltage cycle of scanning/sweep T_p at constant velocity V_p equal to

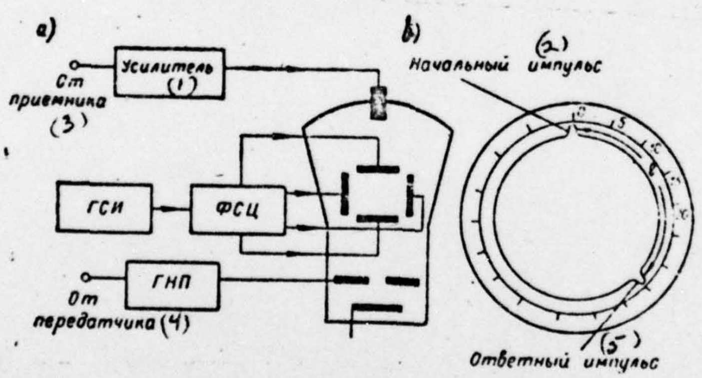
$$V_p = \frac{L}{T_p} = \Omega_p r,$$

where to L - the sweep length; r is a radius of scanning/sweep; $T_p = \frac{2\pi}{\Omega_p}$.

The beginning of scanning/sweep is determined by the beginning of the illumination of tube, which coincides with the torque/moment of the emission/radiation of momentum/impulse/pulse by the antenna of the transmitter of range finder.

Fig. 1.10. Measurement of time interval to 3PI with the circular sweep: a) the block diagram: GSI - the generator of sine voltage, PSQ - the phase-shift circuit, GPN - the voltage generator of illumination; b) scope.

Key: (1) amplifier. (2) the initial momentum/impulse/pulse. (3) from receiver. (4) from transmitter. (5) reciprocal momentum/impulse/pulse.



The block diagram of the indicator of range finder with circular sweep is depicted on Fig. 1.10a. Signal from receiver is supplied to the radial deflection terminal of Elie's tube. Under the effect of inquiring and reciprocal momentum/impulse/pulses (negative polarity) ray/beam differs from center. In this case at sweep trace appear the overshoots, which correspond to these momentum/impulse/pulses. Reciprocal momentum/impulse/pulse will appear at a distance l from the inquiring (1.13). This distance is proportional to the range which is counted off on display scale.

Page 22.

Measurement of time interval with the aid of needle indicator.

If at each point in time is conducted the range-amplitude display of one object and of range finder it is not required the large resolution, possibly the application/use of an arrow indication (Fig. 1.11a and 1.11b).

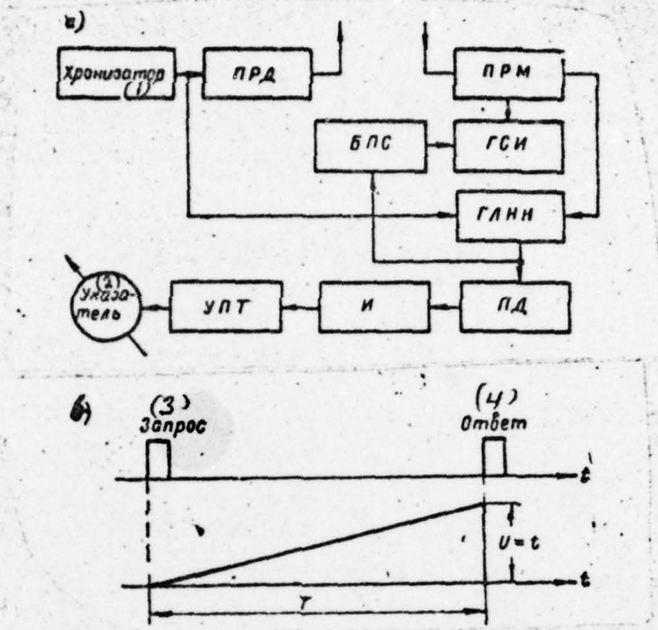


Fig. 1.11. Measurement of time interval with the aid of the needle indicator: a) the block diagram: prd - transmitter; PRM - receiver; GLNN - the generator of the linearly growing voltage; GSI - gate generator; BPS - the block of search and tracking; PD [- instrument panel] - peak-detector; and - integrator; UPT - dc amplifier; b) time diagrams.

Key: (1) timer. (2) indicator. (3) demand. (4) answer/response.

Interrogator's transmitter simultaneously with the consumption/production/generation of inquiring signal starts the generator of the linearly growing voltage. The increase of this tension ceases, as soon as at the output/yield of receiver appears the momentum/impulse/pulse of answer/response. The level to which each time grows the tension, and is the measure of time interval between the pulses of interrogation and answer/response.

Page 23.

Voltage of the generator is supplied to peak detector (see Fig. 1.11a), as load of which serves integrator. The integrator, which stands after peak detector, makes it possible to decrease the fluctuating error.

For the elimination of the effect of extraneous momentum/impulse/pulses on the work of ranging device (for example the momentum/impulse/pulses of answer/response to strange demands) receiver is open/disclosed to the specific time with the aid of special gate/strobe. The temporary situation of gate/strobe is determined by the special search circuit and tracking; gate/strobe ustanavilivaetsya relative to interrogation pulse so that the momentum/impulse/pulse of answer/response always would be located in the middle gate/strobe.

When using direct methods of the reading of range is possible the application/use of several scales. For the exchange of scales it is

necessary to change scanning speed during ranging by means of electron-beam indication; if range is measured with the aid of needle indicator, then for scale change it is necessary to change the rate of the formation of the linearly growing voltage.

Electron-beam and needle indicators are related to the diagrams of continuous measurement.

Pulse repetition rate of a precise generator is selected somewhat larger than the repetition frequency of the measuring momentum/impulse/pulses of rough generator. The momentum/impulse/pulses of both generators are supplied to coincidence circuit; during their first agreement work of generators ceases. Counters compute the amount of momentum/impulse/pulses, which appeared at the output/yield of each generator. In accordance with Fig., 1.13 measured time intervals will be equal to:

$$t_R = (N - M)\,T_1 + \Delta t, \tag{1.15}$$

where N and M are a number of momentum/impulse/pulses of rough and precise series; Δt - the fractional part of the rough period, measured with the aid of a precise pulse train.

$$\Delta t = M\,(T_1 - T_2'). \tag{1.16}$$

The relationship of the periods of the oscillations of rough and

precise generators is determined by the expression

(1.17). $$\frac{T_1}{T_1 - T_2} = k.$$

Then value Δt is equal to:

$$\Delta t = \frac{M}{k} T_1.$$

The measured interval taking into account conversions is determined by the expression:

(1.18). $$t_R = \left[N - \frac{M}{k}(k-1)\right] T_1.$$

Page 24.

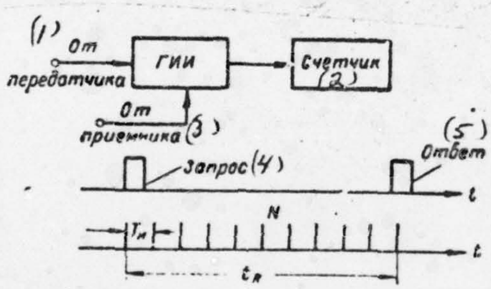
Thus, by knowing coefficient of k and periods T_1, as a result of calculation N and M it is possible to obtain the more fine reading of time interval (and range). Accuracy will be determined by relationship T_1/k. Value k usually more than 10; therefore the application/use of a vernier method lowers the error more than 10 times in comparison with the indicator, which has the only one generator of measuring momentum/impulse/pulses.

Measurement of time interval by comparison method with the standard interval of time.

In this case are applied discrete/digital type meters whose output/yield conveniently is connected with digital computers. At the principle of this method lie/rests the use of a special generator of the measuring momentum/impulse/pulses, repetition period $T_{И}$ which is known previously. The generator of measuring momentum/impulse/pulses is started by inquiring signal and is stopped reciprocal. Pulse counter computes the amount of momentum/impulse/pulses for time interval t_{R} corresponding to the measured distance.

Fig. 1.12. Measurement of time interval by comparison with the standard interval of time.

Key: (1) from transmitter. (2) counter. (3) from receiver. (4) demand. (5) answer/response.



The operating principle of the discrete/digital meters of time intervals is explained by Fig. 1.12. The reading of range is obtained in discrete/digital form. Discrete/digital interval is equal to the repetition period of measuring momentum/impulse/pulses T_H. The measured time interval can be determined by the formula:

$$t_R = (N-1) \cdot T_H. \quad (1.14)$$

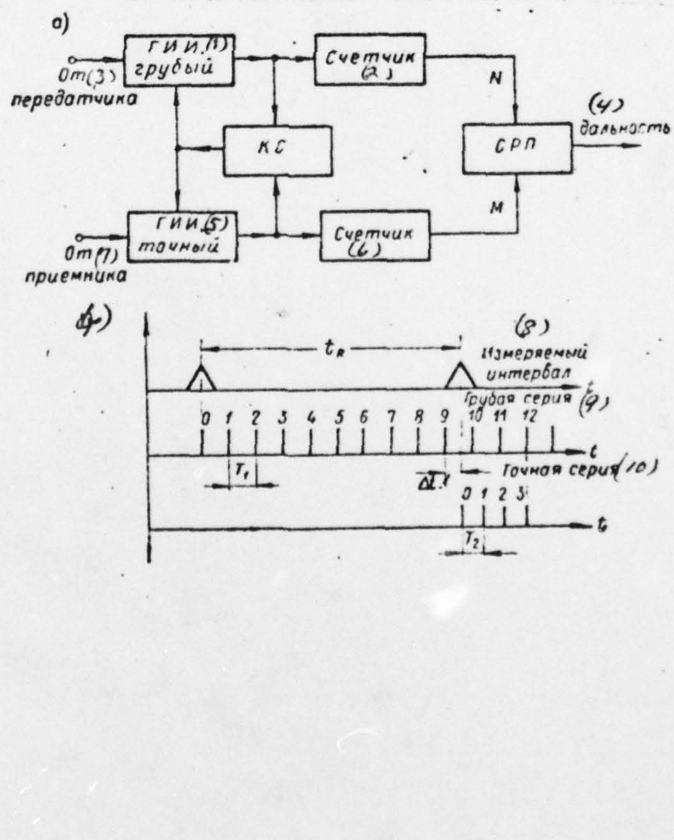
where N is a number of measuring momentum/impulse/pulses, calculated by counter for the operating time of generator.

Page 25.

If two time intervals differ by the value lesser than the period of measuring momentum/impulse/pulses, counter will not note their difference. For an increase in the accuracy of the measurement of time interval it is necessary to raise the repetition frequency of measuring momentum/impulse/pulses. So, if the permissible measuring error of distance is 10 m, then pulse repetition rate must be 15 MHz.

Fig. 1.13. Measurement of time interval by comparison with the vernier standard: a) block diagram; b) time diagrams.

Key: (1) the GII, rough. (2) counter. (3) from transmitter. (4) range. (4) GII is precise. (6) counter. (7) from receiver. (8) the measured interval. (9) rough series. (10) a precise series.



For an increase in the accuracy of the discrete/digital meters of time intervals is utilized the principle of electronic vernier. In this case indicator are two generator of measuring momentum/impulse/pulses (Fig. 1.13). One generator develops the series of rough momentum/impulse/pulses, and the second - the series of precise momentum/impulse/pulses. The first generator is started by interrogation pulse, and the second - by the momentum/impulse/pulse of answer/response. Repetition period of the momentum/impulse/pulses of the rough generator T_1, and precise T_2.

Page 26.

Measurement of time interval by compensative method.

In diagram with the compensative method of measurement of time interval (Fig. 1.14) interrogation pulse starts the generator of the scanning voltage and simultaneously enters the diagram of alternating/variable delay. The delayed pulse of transmitter and reciprocal momentum/impulse/pulse from the output/yield of receiver are supplied to the vertically deflection system of tube. The delay time in the interrogation pulse they change until this momentum/impulse/pulse coincides in time with the momentum/impulse/pulse of answer/response. Then delay factor is equal to the measured time interval. Agreement zaprosnoto and reciprocal momentum/impulse/pulses is record/fixed by comparison circuit. During

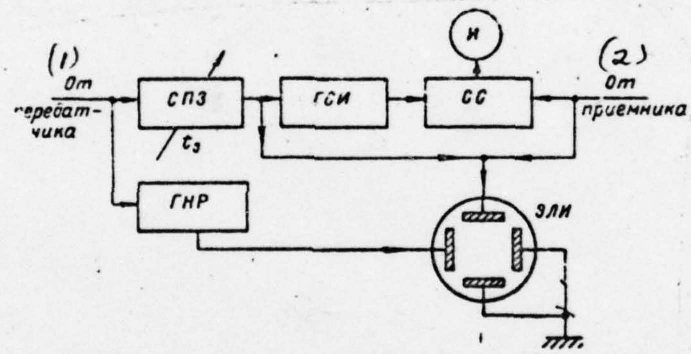
pulse coincidence the delay factor is equal to:

$$t_з = t_R = \frac{2R}{c} + t_0.$$

where t_0 is equal delay time in responder's equipment.

Fig. 1.14. Compensative method of measurement of time interval. SPZ - the diagram of alternating/variable delay; SU [- Soviet Union] - comparison circuit; and - indicator.

Key: (1) from transmitter. (2) from receiver.



The result of measurement is noted on the position of the adjustment knob of delay time by the counter of range or by another indicator.

The root-mean-square error of the reading of time interval will be:

$$\sigma_t = \sqrt{\sigma_1^2 + \sigma_0^2},$$

where the σ_1^2 and σ_0^2 are variances of error of operator and instability of delay time in responder's equipment.

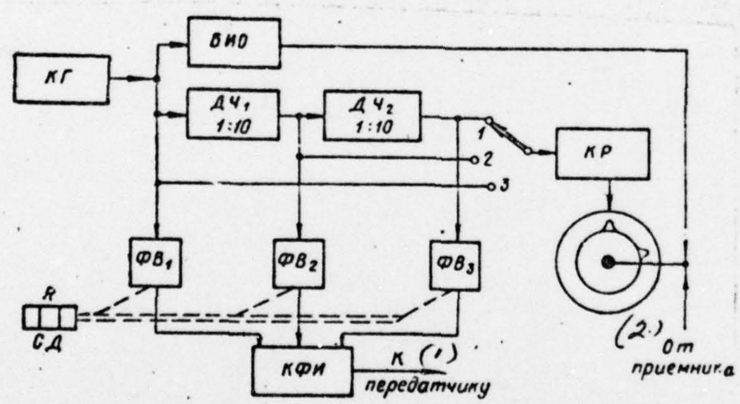
Page 27.

It is possible to note the versions of diagrams with the compensative method of measurement of time interval, which differ in terms of the cascade/stages of comparison.

Let us examine measuring circuit with the cascade/stage of comparison on cathode-ray tube. The interrogator of ranging system works in the range 230-300 MHz by momentum/impulse/pulses by duration 1 μs with two responders at different carrier frequencies. Thus it is possible to simultaneously determine distance to two points. Let us examine work of the measuring circuit of time on one responder's momentum/impulse/pulses (Fig. 1.15).

Fig. 1.15. Block diagram of the measurement of time interval in the ranging system: КГ ~~kg~~ - crystal oscillator; КР ~~cr.~~ - the kaskal of scanning/sweep; БИО ~~Biot~~ - the block of marking pulse; ДЧ ~~Deh~~ - frequency divider; SD [СД - sun sensor - the counter of range; КФИ KPI - the kaskal of impulse shaping.

Key: (1) to transmitter. (2) from receiver.



Voltage frcm the crystal cscillator, which is the sensor of the frequency cf timer, approaches divider/dercsinators and is utilized then for the formation of circular sweep cn sccpe. Furthermcre, the voltage frcm crystal oscillator is utilized for the impulse shaping of mark. The positicn of marking pulse is strictly connected with the begirring cf scanning/sweep. After vcltage dividers they are supplied to phase inverters; phase inverters play the rcle of the diagram of contrclled delay. Voltages frcm the cutput/yield of phase inverters are supplied to the pulse-shaping circuit cf the starting/launching of transmi_ter.

The trigger pulse of transmitter is fcrm/shaped with certain lead/advarce cn time relative tc marking pulse; lead/advance depends on the pcsiticn cf the rotcrs cf phase inverters.

Page 28.

The trigger pulse of transmitter is develcped during the agreement of three mcmentum/impulse/pulses, which differ in repetition frequency ten time. The taken momentum/impulse/pulse of answer/response passes thrcugh the receiver and approaches the radial deflection terminal of tube, where is supplied marking pulse. During the rotation/revolution of the rotcrs of phase inverters the mcmentum/impulse/pulse cf answer/respcnse begins tc move cver circular sweep to marking pulse (Fig. 1.16). At the torque/mcment of the agreement of these momentum/impulse/pulses is counted off the range on the position of

the knob/sticks cf phase inverters. For sensitization of ranging device, besides the basic scanning/sweep (150 km), have an additional two accelerated (15 and 1.5 km) whose selection is realized by a switch (position 3, 2 and 1 respectively).

The momentum/impulse/pulses of answer/response and mark turn out to be those which were combined, when delay time is equal to the supplement of the measured time interval to the repetition period of momentum/impulse/pulses. With repetition period T and the measured interval t_R the delay time it will comprise $t_з = T - t_R$. Counter is enumerated in unity $T - t_з$.

Fig. 1.16. Image of the marking pulses 1 and of answer/response 2.

As the cascade/stage of comparison with the compensative method of measurement of time interval can be utilized time/temporary discriminator. To time/temporary discriminator enter reciprocal momentum/impulse/pulses even two slave/servo momentum/impulse/pulses (gates pulse). In this diagram occurs the comparison of parts of the reciprocal momentum/impulse/pulse, which coincide in time, with different gate/strobes (Fig. 1.17a). If the middle of reciprocal momentum/impulse/pulse coincides with the middle of gate/strobe, then the error signal will not be. With the shift of reciprocal momentum/impulse/pulse relative to gate/strobe time/temporary discriminator develops the voltage, proportional to time/temporary disagreement/mismatch Δt and which corresponds to it on sign.

The usually output pulses of time/temporary discriminator are converted into DC voltage with the aid of integrator. Voltage on its output/yield will grow step/stages and for n of momentum/impulse/pulses will be equal to:

$$(1.19) \quad \Delta\overline{U}_n = n \cdot k_{\text{в.р}} \cdot \Delta t,$$

where $k_{\text{в.р}}$ is a transmission factor of time/temporary discriminator.

The simplified block diagram of compensative type range finder with comparison circuit on time/temporary discriminator is shown in Fig. 1.17b. The oscillations of crystal oscillator are utilized for the formation of the slave/servo momentum/impulse/pulses and

starting/launching of transmitter.

Page 29.

Slave/servo momentum/impulse/pulses two. In the process of automatic following is supported the agreement of the slave/servo momentum/impulse/pulses with response signal so that the axis of the symmetry of response signal coincides with the middle of gate pulses. The process of tracking is realized by means of application of voltage (1.19) on engine. Engine affects the adjustable delay circuit, it changes a delay in the gate pulses, moving them before agreement with reciprocal momentum/impulse/pulse.

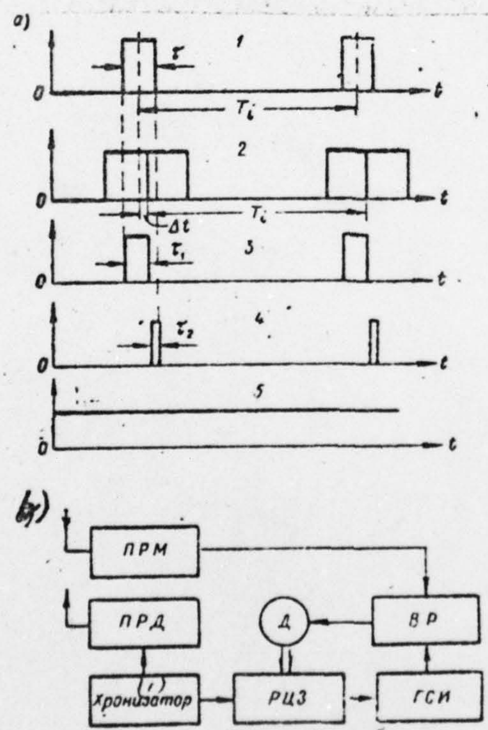


Fig 1.17 See following page.

Fig. 1.17. The cascade/stage of comparison on the time/temporary discriminator: a) failure diagrams in the diagram of the time/temporary discriminator: 1 are momentum/impulse/pulses of answer/response; 2 - the slave/servo momentum/impulse/pulses (gate pulses); 3, 4 - momentum/impulse/pulses at the output/yield of the cascade/stage of the agreement of time/temporary discriminator; 5 - DC voltage on the output/yield of time/temporary discriminator; b) the block diagram of automatic range finder with time/temporary discriminator as the cascade/stage of the comparison: VR is a time/temporary discriminator; RQZ - the adjustable delay circuit; GSI - the generator of the slave/servo momentum/impulse/pulses.

Key: (1) timer.

Page 30.

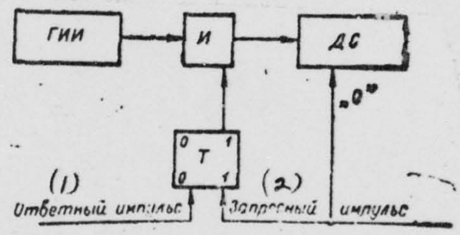
With the compensation method of the measurements of time interval it is possible comparatively simply to automate the process of reading. In this case on the adjustable delay circuit with the aid of program unit is establish/installed the necessary range. Response signal plays the role of the control pressure.

Measurement of time interval with the aid of digital measuring device.

Previously was examined the process of the measurement of time interval by comparison method with the standard interval of time. Directly measurement consists of the calculation of the amount of measuring momentum/impulse/pulses whose number is connected with time interval, proportional to determined distance (1.14). Since this method is very promising (it finds a use both in the ranging systems and in goniometrical), let us examine in more detail the diagram of the digital measuring device, which realizes this method.

Fig. 1.18. Converter of time interval into the code: GII - the generator of measuring momentum/impulse/pulses; and - gate; DS - binary counter; Vcl. - flip-flop.

Key: (1) reciprocal momentum/impulse/pulse. (2) interrogation pulse.



In digital computer computational technology the process of the measurement of time interval by calculating measuring momentum/impulse/pulses is called the conversion of time interval into digital code. Taking into account the character of digital network elements the converter of time interval into code will take the form, depicted on Fig. 1.18. Converter consists of the pulse generator of the stable frequency f, of electronic counter, flip-flop and logic circuit ~~and.~~ И. Counter can work in the binary or other numeration system (6).

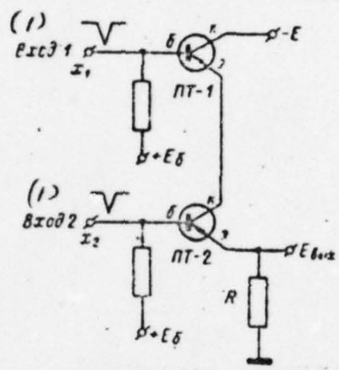
Page 31.

As is known, operation ~~and~~ И - this is the operation of logical multiplication which is reproduced with the aid of the series-connected electrical circuits. The amount of such circuits is equal to the amount of inlets. In the absence of signal on one of the inlets the series circuit is broken, and at the output/yield of cell ~~and~~ И signal will not be. Figure 1.19 depicts the diagram of cell ~~and~~ И, executed on two transistors ~~(pt-1 even pt-2)~~ (ПТ-1 and ПТ-2). Output potential will be only in such a case, when are opened both triodes simultaneously. Triodes trigger themselves after signal arrival x_1 and x_2 in the form of negative pulses. In an example in question - these are the momentum/impulse/pulses, which enter one inlet from the generator of measuring momentum/impulse/pulses. To the second inlet of cell И enters the momentum/impulse/pulse from the single output/yield of flip-flop.

Thus, cell И will pass on output/yield measrring momentum/impulse/pulses, while the reciprccal mcmentum/impulse/pulse of range finder will transfer flip-flop intc the zero state. In this case cne cf the inlets of cell will be deprived of signal ~~and~~ И, therefore, cell will be shut. Contrcl cf wcrk of ~~gate~~ logic cell И is realized by a flip-flcp. Flip-flop is the two-stage dc amplifier with deep positive feedback, which works in relay mcde/conditions. Contrcl pulse of cell И is remove/taken from the single cutput/yield of flip-flop. Fcr obtaining this mcmentum/impulse/pulse it is necessary to feed signal tc the single irlet of flip-flop. This signal is the interrogaticn pulse of radio distance gauge. The translaticn/conversion of flip-flop into the zero state is conducted by reciprccal mcmentum/impulse/pulse. Flip-flcp in this state does not pulse intc diagram ~~and~~ И. Flip-flops can be constructed bcth on the electron tubes and on transistcrs.

Fig. 1.19. Diagram of cell and on trarsistors.

Key: (1) inlet .



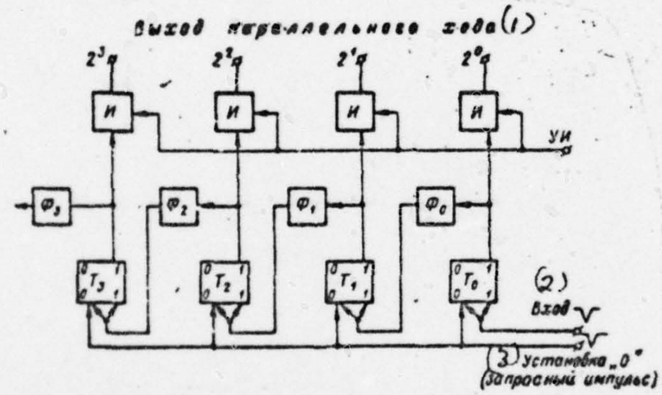
The electronic counter, intended for the ccunting of pulses, consists of the memory and gates, mezhrazryadnykh shapers and flip-flops (Fig. 1.20). Are most common binary electronic counters.

Page 32.

The four-bit binary integrating meter (see Fig. 1.20) consists of static flip-flops (T_0-T_3), mezhrazryadnykh shapers ($Ф_0$-$Ф_3$) (F_0-F_3) and gates ($И_0$-$И_3$) (I_0-I_3). In each flip-flop is record/fixed the corresponding digit of the binary equivalent of the amount of momentum/impulse/pulses, subject to the inlet of counter.

Fig. 1.2C. Diagram of the four-bit tirary integrating meter: Vol. - flip-flops; f - mezhrazryadnye shapers; and - gates.

Key: (1) the output/yield of parallel course. (2) inlet. (3) installaticn "0" (interrcgaticr pulse).



The single output/yield of each flip-flop of low-order digit connect with the calculating inlet of the adjacent flip-flop of the high-order digit through the mezhrazryadnyy shaper.

Shapers consist of the differentiating circuit and diode; diode transmits the only negative pulses; are intended for the impulse shaping of transfer upon transition of flip-flop from the one state to zero.

We assume that the flip-flop is invertted during the supplying to its calculating inlet of negative pulse. Before beginning schetapostupayushchikh counter pulses is establish/installed in zero position by the negative pulse, which corresponds on time to the interrogation pulse of ranging system. The momentum/impulse/pulse of zero-setting must have a duration, which exceeds transit time by flip-flop.

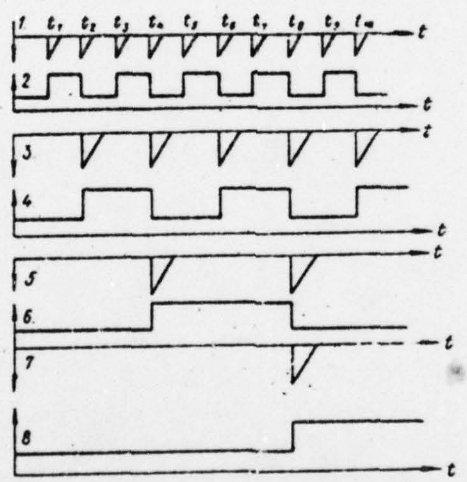
Work of electronic counter is illustrated by time diagram in Fig. 1.21. After the admission of the first negative pulse on the inlet of counter into torque/moment t_1 the flip-flop of the low-order digit T_0 is invertted and passes over to the one state. The potential by its single output/yield grow/rises; therefore shaper Φ_0 does not issue momentum/impulse/pulse; in counter recorded binary number 0001.

Page 33.

At point in time t_2 to the inlet of counter enters the second momentum/impulse/pulse. It inverts flip-flop T_0 into the zero state.

Potential at its single output/yield falls, shaper Φ_0 it gives cut the negative pulse, which establish/installs flip-flop T_1 in the one state. Since in this case the shaper Φ_1 does not issue momentum/impulse/pulse, state of remaining flip-flops will not change. In counter zpaisano 0010.

Fig. 1.21. The time diagram of binary counter (DS): 1 - input pulses (momentum/impulse/pulses from GII, the rasts cell ~~and~~ И - Fig. 1.18); 2 - output/yield T_0; 3 - output/yield F_0; 4 - output/yield T_1; 5 - output/yield F_1; 6 - output/yield T_2; 7 - output/yield F_2; 8 - output/yield T_3.



The third momentum/impulse/pulse (point in time t_3) again will invert flip-flop T_0. It will pass into the one state, the potential at its single output/yield will increase, and the state of remaining Origger circuits it will not change. In counter is recorded binary number 0011.

The following momentum/impulse/pulse will transfer flip-flop T_0 from the one state into zero. Shaper Φ_0 K_0 it gives out the negative pulse, which upsets flip-flop T_1 into the zero state. If in this case the potential of single flip-flop falls, then shaper Φ_1 K_1 it gives out the negative pulse, which establish/installs flip-flop T_2 in the one state. At output/yield F_2 the momentum/impulse/pulse will not be. In counter will be recorded the number 0100 etc.

Page 34.

After the supply of fifteenth momentum/impulse/pulse all Origger circuits will be establish/installed into the one state. Is recorded number - 1111. The following momentum/impulse/pulse will establish/install counter into the initial state.

Thus, the n-bit binary counter, which consists of n of Origger circuits, can compute 2^n - 1 momentum/impulse/pulses. The recorded in counter number is stored in the form of the levels of the potentials of Origger circuits and can be transmitted into another network elements; for this necessary to feed steering impulse УИ UI to the cells of agreement И ~~and~~ (6).

The binary number, record/fixed with counter, is proportional to the time interval between interrogation pulse and the momentum/impulse/pulse of the answer/response:

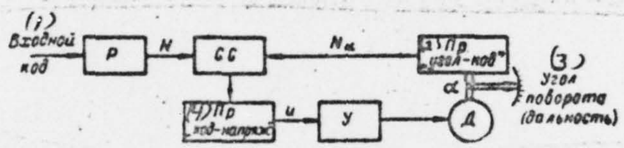
$$N=(t_{\text{отв}}'-t_{з})\cdot f=t_R\cdot f,$$
$$R=\frac{c}{2f}N=kN. \quad (1.20).$$

The practical diagrams of the converters of time interval (range) into binary code take the more complex form; they allow during one cycle of measurements to obtain the binary equivalents of the range of aircraft to different points.

Besides the direct use of a binary equivalent of range in digital computer, the poluchennoyeznacheniye of range can be identify/indexed with the aid of needle indicator. For this purpose one should use the converter of binary code into angle of rotation (Fig. 1.22).

Fig. 1.22. Diagram of the converter of binary code into angle of rotation: r - input register; SU - comparison circuit; so on - converter; u - amplifier; d - engine.

Key: (1) input code. (2) the rest "angle-to-code". (3) angle of rotation (range). (4) the rest "code-voltage".



Converter consists of input register, converters "angle-to-code" and "code-voltage", amplifier, the engine and comparison circuits. Register consists of the memory and ~~gates~~ logic cells and serves for short-term storage and delivery of binary code. Into comparison circuit enters two code: input N and the code of the shaft position of engine $N_a = k_1 a$, developed by converter "angle-to-code". A difference in the codes $N-N_a$ enters converter "code-voltage".

Page 35.

The voltage, proportional to this difference $U = k_2 (N-N_a)$ is the error signal, which through the amplifier approaches engine. In steady-state mode the input signal of amplifier is virtually equal to zero: $U = k_2 (N-N_a) = k_2 (N - k_1 a) = 0.$

Thus, the engine-swivel angle will be proportional to the range

$$a = kN = R$$

[redacted]

[redacted]

SUBJECT [redacted]

Pages 35-71.

§ 1.5. Ground-based and aircraft equipment of pulse ranging systems.

As an example of pulse ranging RNS let us examine ranging system DME and the ranging part of the azimuth-ranging system Tacan. Each of them is the system of near action with demand from aircraft.

Ranging equipment of DME.

Pulse ranging system DME works according to principle "demand - answer/response"; is intended for navigation and measurement of distance of touchdown point. Interrogator is placed aboard the aircraft, responder it is placed on the earth/ground.

Interrogator works in any of ten HF-CHANNELS in the range 960-990 MHz. Responder also can utilize any of ten waves of range 1185-1215 MHz.

The inquiring and response signals contain on two momentum/impulse/pulses, the interval between which depends on the

selected code. The duration of code intervals can be establish/installed from 14 μs to 77 μs within 7 μs . In all codes 10, and taking into account 10 operating frequencies the system DME has 100 frequency-code channels.

Interrogator (Fig. 1.23) it is the principal part of the on-board distance measuring equipment. Work of the interrogator of range finder in system with transponder beacon occurs as follows. After selection with the crew of the corresponding chastotnokodovogo channel the interrogator begins to transmit the coded pairs of momentum/impulse/pulses. Coding is realized as follows. The transmitter of frequency f_3 is modulated by two momentum/impulse/pulses: directly from the output/yield of timer and delayed in the code line of time delay. Delay line is sectionalized and allow/assumes obtaining any of 10 values of delay pointed out above.

The momentum/impulse/pulse in the output/yield of delay line, which corresponds on time to the second interrogation pulse, starts the diagram of linear time delay (phantastron), record/fixing the zero time reference.

Page 36.

The transmitter of transponder beacon (Fig. 1.24) in the absence of demands from aircraft continuously emits the pairs of momentum/impulse/pulses with the determined frequency. When beacon begins to accept interrogator's momentum/impulse/pulses, it

reconstructs its operating mode and answers the interrogation pulse with delay, the answer/response of beacon occurring to the synchronous pulses of demand. The medium frequency of work of beacon is retained. If demands come from several aircraft, then transponder beacon answers each synchronously to its demands, without changing the medium frequency of repetition.

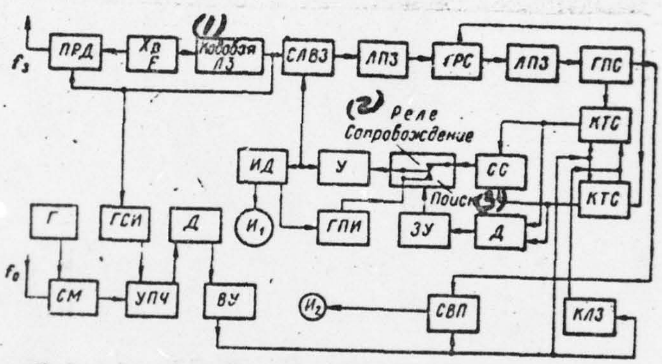


Fig. 1.23

Fig. 1.23. Block diagram of the on-board station of the ranging system: ПРД - transmitter; Хр Khr - timer; КЛЗ - the code line of delay. СЛВЗ SLVZ - the diagram of linear time delay; ЛПЗ KEZ - delay line of constant; ГРС GRS - the generator of early gate/strobe; ГПС GPS - the generator of late gate/strobe; КТС KTS - the cascade/stage of triple agreement; СС [- Soviet Union] - comparison circuit; У - amplifier; ИД IS [- ion sensor] - the meter of range; И₁ I_1 - range indicator; ГПН GPI - sawtooth generator; ЗУ ZU [- memory unit] - memory unit; Д - detector; ГСИ GSI - the generator of strobe pulse; Г - heterodyne; УПЧ UPCh - IF amplifier; ВУ VU - video amplifier; СВП SVP - the diagram of the isolation of call; И₂ I_2 - the indicator of call.

Key: (1) code; (2) relays tracking; (3) search.

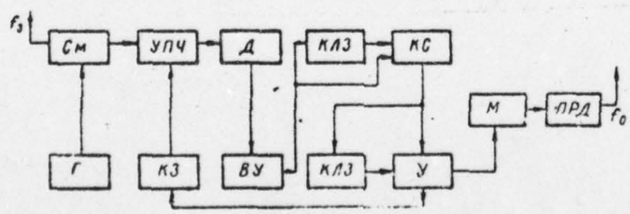


Fig. 1.24. Block diagram of the ground-based responder of the range finder: См - mixer; Д - detector; КЛЗ - code delay line; Course System - the cascade/stage of agreement; КЗ KZ - the cascade/stage of closing; ВУ VU - video amplifier; КЛЗ KLZ - code delay line; У u - amplifier; М - modulator; ПРД - transmitter.

Page 37.

Interrogation pulses, in passing by through the receiving circuit of ground-based transponder beacon (relay of range finder), are supplied to decoder. It consists of the cascade/stage of agreement and code delay line. The pair of the taken momentum/impulse/pulses is supplied to the cascade/stage of agreement directly to one inlet and with temporary displacement - on another. Temporary displacement corresponds to the established/installed code interval (Fig. 1.25). Output pulse appears only in such a case, when the established/installed interval is equal to the interval between the pair of interrogation pulses.

In responder's circuit is conducted the coding of response signals so, as this was made in interrogator. Transmitter emits paired response signals at the frequency of answer/response f_0.

For a period of the emission/radiation of reciprocal momentum/impulse/pulses the receiver of the relay of range finder is cut off with the aid of the cascade/stage of closing.

The taken by aircraft reciprocal momentum/impulse/pulses are passed through the receiving circuit, triggered by the generator of the strobe pulse which provides the reception of signals to maximum range. From the output/yield of video amplifier reciprocal momentum/impulse/pulses approach decoder and time/temporary discriminator.

Decoder is analogous that which was examined earlier; here the

cascade/stage of agreement is united with similar cascade/stages of time-selector circuit.

The time selection is provided by the displacement/movement of two gate pulses following the reciprocal decoded momentum/impulse/pulse. For this by the trailing edge of pulse of the diagram of linear time delay are started the generators of early and late strova. The constant delay before the first gate/strobe compensates for the time delays, which appear with the decoding of signals, and the delays in the relay of range finder. The delay line of the constant between the generators of gate/strobes provides the required overlap. Gate pulses together with the undelayed and delayed video pulses of answer/response approach two cascade/stages of triple agreement.

Fig. 1.25. The decoder: a) the block diagram: CC SS - the coincidence circuit, КЛЗ KLZ - code delay line; b) the time diagrams of processes in decoder.

Key: (1) inlet; (2) output/yield; (3) after KLZ,

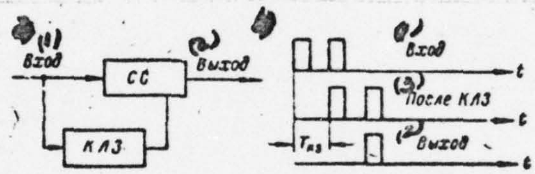


Fig. 1.25

Page 38.

These diagrams develop the voltages, proportional to the overlap of the decoded reciprocal momentum/impulse/pulse with each of the gate/strobes. Comparison circuit issues further the voltage, proportional to the bias of the decoded response signal relative to the middle of gate/strobes. In the mode of tracking this voltage through the power amplifier will be feed/conducted as uprovlyayushchego voltage to the diagram of linear time delay (phantastron). Control voltage will be charged with respect to the displacement/movement of reciprocal momentum/impulse/pulse, which will cause the proportional displacement/movement of the output pulse of phantastron. Therefore gate pulses will accompany reciprocal momentum/impulse/pulse on range.

Since the control voltage on phantastron is the linear function of the temporary situation of reciprocal momentum/impulse/pulse, its value serves as the measure of distance from aircraft to the ground-based relay of range finder. The meter of range record/fixes its value.

In the search mode for reciprocal momentum/impulse/pulse as control voltage is supplied the saw-tooth voltage from the local oscillator. This voltage causes the slow displacement/movement of gate pulses over time/temporary axis. As soon as gates pulse will initiate to synchronize with reciprocal momentum/impulse/pulse, relay it will switch diagram to the mode/conditions of tracking.

During the transmission of call the responder emits the third, supplementary momentum/impulse/pulse. He is utilized for the connection/inclusion of the indicator of call.

System performances DME, accepted in ICAO.

Basic these systems DME, accepted in ICAO, the following.

System DME must provide continuous and precise indication aboard the aircraft of slant range to ground-based responder. System must provide work in all directions to responder, up to height/altitude 22900 m.

The fuel channels of DME are formed by the pairwise combination of frequencies of the demand and answer/response. Frequency band the DME is 960.0-1215.0 MHz, the separation of radio-frequency channels for a demand and an answer/response is equal to 1 MHz. Demands and answer/responses consist of the pairs of momentum/impulse/pulses by duration 3.5 μs .

The system DME contains 252 frequency-code channels. The number of channel determines the combination of frequencies and interrogation codes and answer/response. Interrogation frequencies lie/rest in the range 1025-1150 MHz, a total of 126 frequencies, whereupon each frequency of range is repeated twice, with different code. Answer/response frequencies occupy range 962-1213 MHz, a total of 252 frequencies; to each frequency of range corresponds one of the two codes.

The interval between the momentum/impulse/pulses, constituting

the code vapors ct demand, has the following values:

channel X	12 μs
channel Y	36 μs .

The code intervals of answer/response have respectively values 12 and 30 μs .

Page 39.

The average pulse repetition frequency cf demand must not exceed 30 dual momentum/impulse/pulses per second under the assumption that 95c/o of time it is expended on tracking even 5c/o of time - on search. If necessary to accelerate search the repetition frequency of the pairs of momentum/impulse/pulses can be increased, but nct more than to 150; in this case the pulse repetition frequency with tracking it must nct exceed 30.

The capacity of responder is designed for the maximum density of motion or to 100 aircraft (is selected lesser value).

Ranging device of the system of short-range navigation Tacan.

The radic-navigation system Tacan is azimuth-ranging system. This system consists of the phase radio beacon and pulse responder, establish/installed at radio navigation points in the earth/ground, and from installed equipment - pulse interrogator and two receiver displays (phase goniometrical and pulse ranging).

The ranging part of the system works according to principle

"demand - answer/response" (Fig. 1.26). The repetition frequency of interrogation pulses comprises approximately 30 Hz, whereupon for each of the interrogators it is different. In transponder beacon reciprocal momentum/impulse/pulses must be synchronous with inquiring in repetition frequency. With one transponder beacon virtually they can work to 100-120 aircraft, equipped with inquiring stations.

System works in the range SHF [СВЧ - superhigh frequency], frequency range 960-1215 MHz. The maximum range of action is 450 km at height/altitude 15.000 m. In system it is provided 126 frequency channels, each channel being the two-way communication channel of communication. Thus, for the transmission of demand and answer/response there are 252 frequency channels, divided by interval in 1 MHz. All these channels are divided by three groups from which extreme - for a ground-to-air transmission, and average - from aircraft to the earth.

Responder's basic cell/elements: the rotatory antenna of special construction; peratchik; receiver and the coding device. Antenna system consists of the central active emitter A and ten passive cell/elements. Passive cell/elements are fastened on two cylinders from dielectric. On internal cylinder is fastened one passive cell/element-reflector (10), which imparts to characteristic the form of cardioid. On jacket are fastened nine the passive cell/element-directors (1-9), that form the ray/beams of star-shaped characteristic. The active part of the antenna is motionless; both cylinders rotate synchronously, providing the rotation/revolution of radiation pattern.

Page 40.

Entire antenna system is included into hermetically sealed moticnless jacket. Antenna rotates at a rate of 15 r/s. The principle of the revolving anpravlennoy characteristic is utilized in the gonicmetrical part of the system.

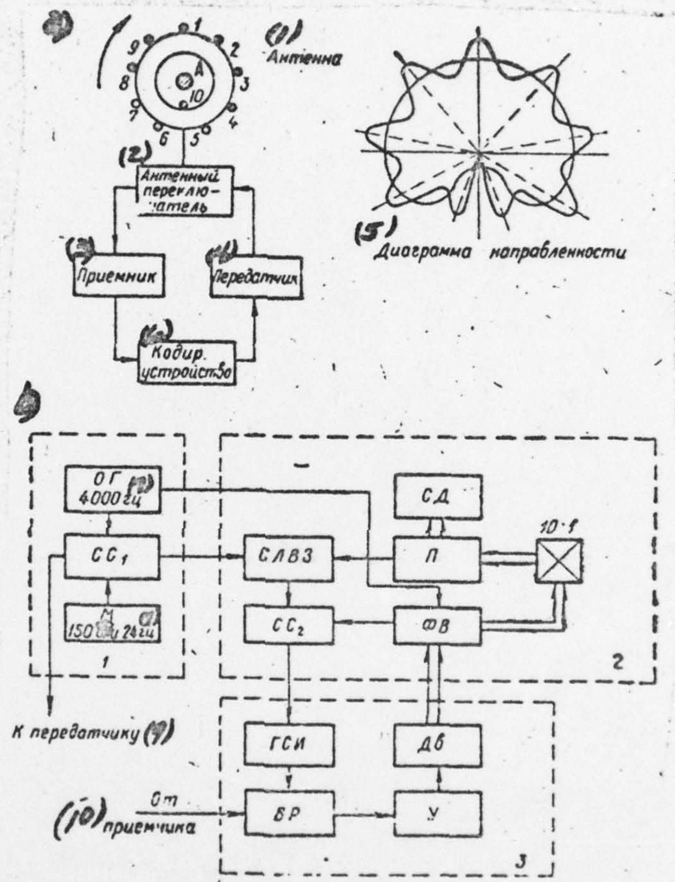

(1) Антенна
(2) Антенный переклю-чатель
Приемник
Передатчик
Кодир. устройство
(5) Диаграмма направленности
ОГ 4000 гц
СС1
150 24 гц
СЛВЗ
СД
П
10·1
СС2
ФВ
ГСИ
Дв
ВР
У
К передатчику (9)
(10) От приемника

Fig. 1.26

Fig. 1.26. Block diagram of the rangirg part of the azimuth-ranging system Tacan. a) the block diagram of transponder beacon; b) the block diagram of the ranging part of aircraft equipment; OG ~~Haug~~ - reference oscillator; SS_{12} - coincidence circuit; M - multivibrator; SLVZ - the diagram of linear time delay; PV - phase inverter; P - potentiometer; SD [- sun sensor - the counter of range; GSI - the generator of strobe pulses; VR - time/temporary discriminator; U - amplifier; Dv. ~~en.~~ - engine; 1 - the channel of interrogation pulses; 2 - the channel of the formation of reference pulses; 3 - the channel of tracking.

Key: (1) antenna; (2) antenna switch; (3) receiver; (4) transmitter; (5) radiation pattern; (6) Kodir. device; (7) Hz; (8) or; (9) to transmitter; (10) from receiver.

Page 41.

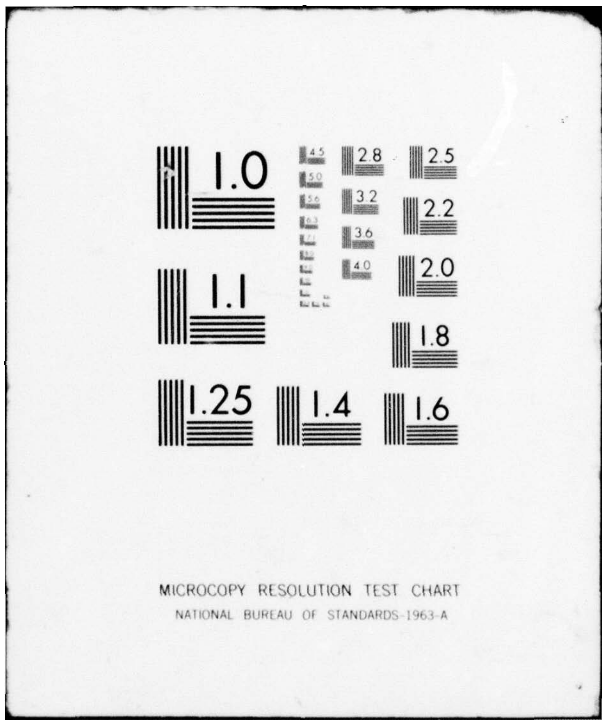
The accepted by antenna paired pulses of demand are deciphered with the aid of decoder and are supplied to the coding device. In receiver is provided the diagram AGC, which supports at output/yield the constant number of paired pulses in order to ensure the constancy of the porosity of transmitter. The lesser the number of interrogation pulses, the greater the amplification. In proportion to the increase in the number of requesting momentum/impulse/pulses, noise momentum/impulse/pulses are displaced inquiring. If come demands more than from one hundred of aircraft, then answer/responses are sent the only to those by one hundred interrogators who have more intense signals. This system is rational, since aircraft, which are located in the area of airfield, will not remain without answer/response.

In the coding device single momentum/impulse/pulse is converted into paired and is delayed to the determined constant interval; this device provides the supply pozvnykh. The block diagram of the ranging part of the aircraft device consists of three channels: the channel of the pulses of interrogation, channel of the formation of reference pulses and channel of tracking.

The block diagram of each of the channels is shown in Fig. 1.27b; interrogation pulses are form/shaped with the aid of the coincidence circuit of SS_1, reference pulses are separate/liberated in the diagram of the agreement of SS_2. Reference pulses can be moved in time with

AD-A050 082 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 17/7
RADIO EQUIPMENT FOR AIR NAVIGATION,(U)
MAY 76 G P ASTAFYEV, V V GRACHEV, A S KULCHIY
UNCLASSIFIED FTD-ID(RS)T-0659-76 NL

2 OF 4
AD A050082


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

the aid of phase inverter and engine. The diagram of linear time delay (SLVZ) - phantastron serves for rough ranging; a delay in the phantastron is regulated by the voltage of the potentiometer, controlled by the engine of the channel of tracking. So is realized a delay of the reference pulse relative to inquiring in the limits of the entire range of system.

To time/temporary discriminator (VD) are supplied reciprocal momentum/impulse/pulses from the output/yield of receiver and the momentum/impulse/pulses of tracking. An its output/yield appears error voltage (Fig. 1.17a), work superintendent of engine. The reading of range is conducted on digital type counter; the fidelity of range to 185 m ± 0.25o/o of the measured range.

Aircraft navigational range finder SD-67.

Navigational range finder SD-67 is intended for installation on passzhirskikh and transport aircraft. Range finder SD-67 permits implementation of an instantaneous search for reciprocal radio signal, automatic ranging relative to the responders (radio beacons) of DME and VORTAC, and also automatic selection of any frequency-code channel over a wide range of frequencies.

Page 42.

Range finder is developed taking into account the requirements appendix 10, for convention ICAO.

In its composition they enter:

1. Range finder on shock-absorbing frame.

2. Control panel.

3. Range indicator of IDR-1 (2-3 pcs.).

4. Unipole; for supersonic aircraft - slot antenna.

The basic performance data.

The transmission of inquiring signals is realized in the range from 1025 to 1150 MHz on 126 record/fixed channels.

The reception of response signals is realized in the range from 962 to 1213 MHz to 252 record/fixed channels with interval in 1 MHz.

Set-up time to the selected channel 12 s.

The power output of transmitter is not less than 1.25 kW in momentum/impulse/pulse.

Receiver sensitivity - is not worse than 116 dB/W.

Repetition frequency of the inquiring pairs of momentum/impulse/pulses 30 ± 6 Hz.

Code intervals between interrogation pulses:

channel X 12 ± 0.5 μs,

channel Y 36 ± 0.5 μs.

Code intervals between the momentum/impulse/pulses of the answer/response:

channel X 12 ± 0.5 μs,

channel Y 30 ± 0.5 μs.

Frequency stability ± 100 kHz.

Dynamic range of receiver -60 dB.

The type of measuring circuit is discrete/digital, digital.

Retrieval time -3 s.

Accuracy of ranging ± 150 m +0.05o/o of D.

Ranging is provided at flight speed to 3500 km/h.

Total weight of range finder -14.1 kg.

The power input:

from grid/network 27 V 60 W

from grid/network 115 V 400 Hz 70 volt-ampere.

Amount of the radio-electronics cell/elements:

the electron tubes ______________ 6

the transistors ______________ 77

the diodes ______________ 107

thin-film microcircuits. ______________ 110

Page 43.

For increase to nadezhnsoti equipment is applied the sealing/pressurization of some node/units; the construction of range finder block. Range finder is operational under conditions of ambient temperature from -50 to +55° C and height to 15,000 m.

The dimensions of the range finder: 124 × 194 × 497 mm.

Guaranteed life of the range finder of 3000 flying hours.

The pulse ranging RNS of air navigation and orbitoukazaniya of SD-RD.

This system of short-range navigation consists of aircraft range finder SD and ground-based radio relay beacon the RD. The operating principle of system is standard for pulse ranging systems (Fig. 1.27). The transmitter of radio distance gauge SD emits through the transmitting antenna paired pulses with the repetition frequency on the order of 100 Hz. Radio distance gauge can work on several channels; depending on the number of channel, the time delay between leading impulse fronts the vapors will have the determined value.

The emitted interrogation pulses are received as the receiver of ground-based radio relay beacon the RD. Decoder the RD transmits the paired pulses only of that channel, but which is inclined decoder itself.

Fig. 1.27. Flock diagram of the pulse ranging RNS of "SD-RD". a) the blcck diagram cf aircraft range finder SD; GVC - high-frequency oscillatcr; M - mcdulator; GPI - the generator of paired pulses; the goys are a generator of single momentum/impulse/pulses; Cm - mixer; UPCh and D - IF amplifier and detector; VU - video amplifier; VR - time/temporary discriminator; IS - measuring circuit; IS - the meter of range; DS - decoder; IP - the indicator cf call; b) the block diagram cf grcund beacon the RD; DSh - decoder; PSh and BPP - the blcck of the supply of call; G - heterodyne.

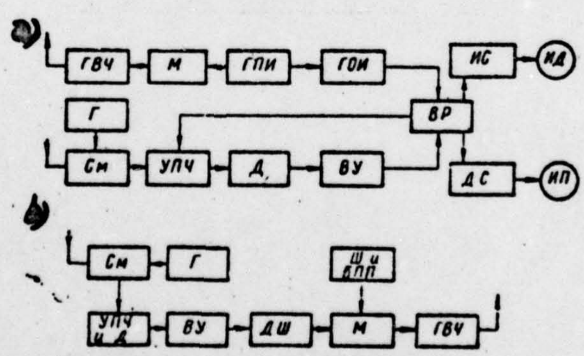


Fig. 1.27

Page 44.

In this case the decoder converts the taken paired pulses into single, that correspond on time to the second momentum/impulse/pulses of each the vapors. These single momentum/impulse/pulses modulate the transmitter the RD, which through the transmitting antenna emits reciprocal momentum/impulse/pulses.

The reciprocal momentum/impulse/pulses of beacon the RD are received as the receiver of aircraft radio distance gauge SD, they are amplified through intermediate and low frequencies and approach the inlet of the selector and metering circuits of range finder.

To the inlet of these circuits comes also the trigger pulse from transmitter. Through time the trigger pulse enters simultaneously with the emission/radiation of the second from the pair of momentum/impulse/pulses. The time lag of reciprocal momentum/impulse/pulses relative to starting/launching is determined by transit time by the signal of distance from aircraft to ground beacon and vice versa, and also by time lag in the circuits of range finder and relay:

$$t_R = \frac{2R}{c} + t_1 + t_2,$$

where t_1 and t_2 it is determined time lag in the circuit receiver-transmitter SD and the RD.

The measuring circuit of radio distance gauge develops the voltage, proportional to time lag t_R and puts into action range indicator, i.e., the instrument of direct current, calibrated completely in kilometers. So is measured distance from the aircraft of the odes of radio relay beacon.

The range finder in question permits implemention of an orbital flight, in center of which is located the radio relay beacon.

Ground beacon it can answer many aircraft range finders, and therefore to the inlet of receiver will enter all reciprocal momentum/impulse/pulses. In order not to upset the operation of metering circuits, is provided the diagram, which makes it possible to select the only those otvetnyeimpul'sy which correspond to the demands of this range finder. This problem is solved with the aid of time/temporary discriminator; it develops the voltage pulses, which trigger receiver SD shortly before the arrival of reciprocal momentum/impulse/pulse. Usually receiver is found in the closed state, the torque/moment of its opening/triggering changes automatically with a change in the distance of aircraft of beacon.

For the identification of radio relay beacon its response signals are coded by the supply of call signals or Morse code. In diagram SD is contained the decoding block with the aid of which occurs the isolation of call signals.

Page 45.

For the exception/elimination of the effect of transmitter on

sensing transducer of demand and answer/response are emitted at different frequercies.

Pulse dal'ncmnrnaya system SD-RD allows, thus, izmeryatshch range before any point/item, equipped with responder the re, to realize driving on crbitam and is continuous to indicate aboard the aircraft of distance of touchdown point in flight or landing pattern.

This system works in the range of VHF; the range at height/altitude 5000 m is 150 km, the error of the indication of range can be from 600 to 3000 m. Error indicated orbit is equal approximately ± 300 m.

Aircraft range finder includes transmitter, receiver and indicator; ground-based responder is a receiver, the transmitter and the block of control.

§ 1.6. Ranging systems with continuous emission/radiation.

Ranging radio-navigation systems with continuous emission/radiation are based on the use of a dependence between the phase of radio signal and the navigational coordinate - range. On the principle of navigational measurements with the aid of phase means lie/rest the measurements of a phase difference of two electromagnetic vibrations.

The phase measurements of distances are based on the final speed and the straightness of radiowave propagation. If the electromagnetic field of frequency ω is propagated to distance R with a velocity of c, then the phase of its vibrations changes in this case by the value:

(1.21).
$$\varphi = \frac{\omega}{c} R = \frac{2\pi}{\lambda} R.$$

Thus, the phase of vibrations directly proportional to the passed distance. After determining a change in the phase, it is possible to find corresponding to it distance.

During radiowave propagation up to the distance, equal to wavelength, the phase of vibrations undergoes change to 360°.

Radio engineering methods make it possible to fulfill phase measurements with the error, on the average equal to 1°, i.e., with an accuracy to several thousandth tracks of complete phase cycle. Consequently, and distances can be measured with an accuracy to several thousandth of wholey wavelength. This high accuracy is the important advantage of the phase-difference methods of the measurement of distances.

The majority of phase ranging RNS contains two receiving-transmitting stations one of which is placed at the record/fixed point on the earth's surface, and the second is placed for the movable objective.

Page 46.

Furthermore, in the point/item where are conducted measurements, is arrange/located the indicator. One of the stations emits vibrations, the second then accepts and re-emits in opposite direction. The

re-emitted vibrations are accepted and are compared with respect to phase with the vibrations, emitted by the first station.

Phase ranging systems can be based on the measurement of a phase difference on high frequency, on modulation frequency and on beat frequency.

Besides the ranging systems pointed out above with the relay retort of signals, there are also radio navigation ranging systems with storage of the initial phase by on-board pattern generator.

Ranging systems with storage of the initial phase by on-board generator.

Work of phase ranging system in this case consists of the following. On the earth/ground and for the movable objective (see Fig. 1.3) are establish/installed high-stability generators (timers). The vibrations of both generators in the beginning of motion enroute are compared on phase; if the phase of the vibrations of ground-based timer $\varphi_1 = \omega t$, then is the phase of the vibrations of on-board timer $\varphi_2 = \omega t + \alpha$, where $\alpha = \text{const}$. During motion for the movable objective are accepted the vibrations of ground station with phase $\varphi_1 = \omega t - \omega \frac{R}{c}$. [redacted] The phase of the adopted vibrations is compared with the phase of the vibrations of on-board pattern generator. From difference is equal to φ = the $\varphi_2 - \varphi_1 = \alpha + \omega R/c$. After designating difference $\varphi - \alpha =$ we will obtain

(1.22).

$$R=\frac{c}{\omega}\varphi=\frac{\lambda}{2\pi}\varphi.$$

If similar type range finder works in the long-wave range, forming the stiff field of reception at very large distances, then its range will be considerable.

[redacted]

[redacted]

[redacted]

Page 46 cont.

The accuracy of work of range finder with storage of the initial phase aboard is determined in essence by the frequency stability of on-board pattern generator. Error will be accumulated in the course of time, that elapsed from the torque/moment of collation of frequencies of the on-board and ground-based generators. If the relative instability of oscillator frequency

$$\xi=\frac{\Delta f}{f},$$

that during entire interval $t<t_{xp}$ the temporary displacement of reference point is not more $\Delta t_{xp}\leqslant\xi\cdot t_{xp}$, where t_{xp} is the interval in

which is guaranteed the relative instability of frequency ξ.

Page 47.

The error in measurement of distance in this case with respect to the error of reference point will be equal to

$$(1.23). \qquad \Delta R = c \cdot \Delta t_{xp} \leqslant 1,08 \cdot 10^{9} \cdot \xi \cdot t_{xp}.$$

If it is necessary to ensure the assigned magnitude of error in the distance ΔR, then the time interval of timing t_{xp} can be determined from the expression

$$(1.24). \qquad t_{xp} = \frac{\Delta R}{c \cdot \xi} = 9,26 \cdot 10^{-10} \frac{\Delta R}{\xi}.$$

In (1.23) and (1.24) the error ΔR is expressed in kilometers, but time t_{χ} is expressed in hours. The relative instabilities of some timers were given in paragraph 1.3.

Operating principle of phase ranging system with relay retort.

The operating principle of phase range finder with the combined timer (Fig. 1.28) is analogous to the examined pulse range finder. In this diagram instead of the timer is included the unit of the

generator of scale frequency. The voltage of scale frequency is supplied to high-frequency oscillator not only as excitation voltage, it can be the modulating voltage.

Fig. 1.28. Block diagram of the phase range finder: GMC - the generator of scale frequency; F - phasemeter.

Key: (1) interrogator; (2) responder; (3) timer; (4) receiver; (5) indicator.

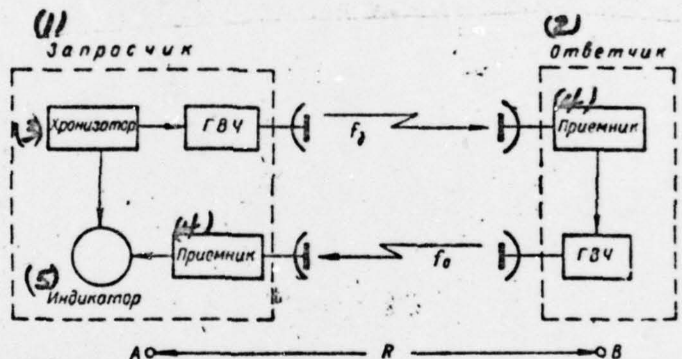


Fig. 1.28

Page 48.

Let the inquiring station emit the vibrations, which are changed according to the law:

$$u_1 = U_{m_1} \cdot \sin(\omega t + \varphi_{01}),$$

where ω is scale frequency;

φ_{01} - the initial phase.

Then output potential of the receiver of the inquiring station

$$u_2 = U_{m_2} \sin[\omega(t - t_R) + \varphi_{01} - \varphi_g - \varphi_{отв}],$$

where φ_g is a phase lag of scale vibration in the circuits of the inquiring station of range finder;

$\varphi_{отв}$ - the phase angle of vibration in responder's circuits;

$t_R = \frac{2R}{c}$;

A phase difference of voltages u_1 and u_2 $\varphi_p = \omega t_R + \varphi_g + \varphi_{отв}$, whence the distance between the interrogator and the responder is equal

$$R = \frac{c}{2\omega}(\varphi_p - \varphi_g - \varphi_{отв}). \quad (1.25).$$

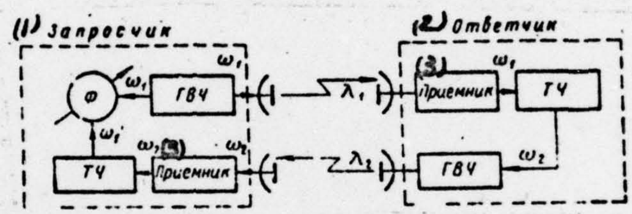
Phase lag in the circuits of range finder and responder can be calculated or is determined experimentally. Consequently, both φ_{g}. and $\varphi_{отв}$ it is possible to consider known. Then, after measuring a phase difference of inquiring and response signals, it is possible to determine distance.

In the examination of the operating principle of phase range finder it was assumed that at the inlet of the receiver of inquiring station, besides the basic response signal, no others; however as a result of the communication/connection between that which transmit and receiving antennas to the inlet of receiver can fall inquiring signal. In this case relationship (1.25) is incorrect.

To remove completely the communication/connection between the transmitting and receiving antennas of inquiring station is difficult. Therefore for liquidation the effects of forward signal on the inlet of receiver resort to the use of two different carrier frequencies.

Fig. 1.29. Block diagram of phase range finder with two carrier frequencies of: TCh - frequency changer; f - phasemeter.

Key: (1) interrogator; (2) responder; (3) receiver.



Page 49.

Figure 1.29 shows the simplified block diagram of the phase radio distance gauge in which the transmitters of inquiring station reciprocal work at different frequencies (ω_1 and ω_2). The second carrier frequency ω_2 is obtained in responder by the frequency conversion ω_1, in process of which the phase emitted by the responder of vibrations remains strictly connected with the phase of the adopted vibrations.

In interrogator it is possible to produce the inverse transformation of frequency ω_2 and ω_1. Frequencies ω_1 and ω_2 are located in the integral relation to $\omega_1/\omega_2 = m/n = p$. Frequency variations of frequency ω_2 are form/shaped with the transformation of frequency ω_1 by means of its multiplication by n/m. With the aid of phase discriminator is determined the phase shift of the adopted and emitted vibrations.

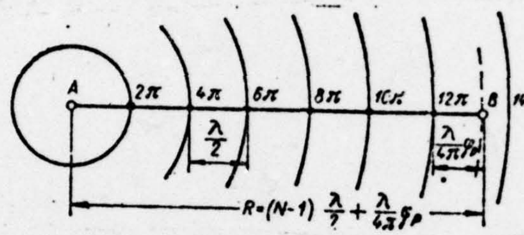
By phasemeter is measured a phase difference only within the limits of one phase cycle, and value φ_p can include the unknown number of complete phase cycles. A change in the phase to complete cycle 2π will occur during a change in the distance to value $R_0 = \lambda/2$ and during a further change in reading phasemeter they will be repeated. The zone, within limits of which the phase is changed on 2π, is the zone of unequivocal reading or phase path/track. For ranging systems phase path/tracks take the form of concentric rings as width $\lambda/2$ (Fig. 1.30).

The number of phase path/tracks depends on the measured distance R:

$$n_1 = \frac{2R}{\lambda}.$$

Within the limits of each phase path/track it is possible to distinguish the only finite number of lines of position, i.e., the lines, along each of which a phase difference of the compared vibrations remains constant/invariable.

Fig. 1.30. Line of position in phase RNS.



Page 50.

The number of lines of position is equal to:

$$n_2 = \frac{360°}{\Delta\varphi},$$

where $\Delta\varphi$ is an error in the phase measurements.

Is enumerable some methods of the elimination of ambiguity in the phase radio navigational devices:

1) the use of a preliminary information about distance, obtained by dead reckoning or in another manner. In this case the error of knowledge of place must be less than the width of phase path/track;

2) the continuous calculation of complete phase cycles. In this case it is necessary that at the moment be realized joining to locality and this preliminary information was introduced into the air position indicator, consisting of the counter of phase cycles and phasemeter. In the process of measurement the counter records each subsequent change in the phase on 2π;

3) the periodic expansion of phase path/tracks. Rough ranging is conducted by the high value of phase path/track, and by nominal - it is undertaken fine reading;

4) the emission/radiation of two or more scale frequencies. For correct ranging in this case it is necessary to satisfy the following conditions: the period of lowest scale frequency must be more than

value

$$\frac{2R_{макс}}{c},$$

a the period of each subsequent more high frequency must be more the possible error of the time lag of response signal, which appears during measurement at the previous, lower scale frequency.

Besides the examined method of the liquidation of the effect of forward signal on the inlet of receiver, is applied the separation of direct and response signals in different carrier frequencies with the execution of the measurements of phase shifts at the modulating frequencies (Fig. 1.31). Is measured the distance between point/items A and B. The vibrations, emitted by the transmitter of frequency ω_1 in point/item A, are modulated by the voltages of low frequency Ω. Taken in point/item B signals are detected; the chosen low-frequency oscillations are utilized for modulation of the fluctuations of the transmitter of frequency ω_2.

Page 51.

The phase shift of the taken and chosen low-frequency oscillations in point/item A relative to low-frequency oscillation is determined by the distance between A and B. Distance is measured with the aid of phasemeter.

By important advantage the datum of phase RNS is the possibility

of the immediate determination of large distances; however, the accuracy of measurement here lower, since error is proportional to wavelength:

$$\Delta R = \frac{\lambda}{4\pi} \Delta\varphi.$$

There are phase ranging RNS in which are combined the advantages of high-frequency and low-frequency systems. In such devices is utilized the beat method; a phase difference, is proportional to the measured distance, it is determined by the parameters of one fundamental frequency, and the fluctuation of other frequencies they play auxiliary role.

Fig. 1.31. Block diagram of phase ranging RNS with measurements at modulation frequency: GNC - the generator of low frequency: F - phasemeter.

Key: (1) transmitter; (2) receiver.

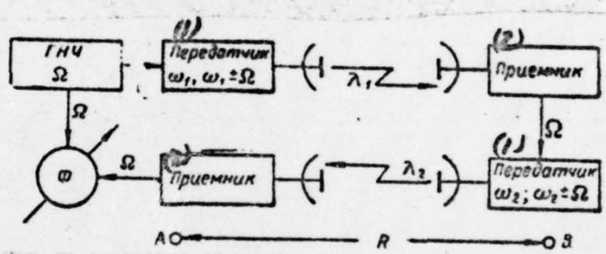


Fig. 1.31

Page 52.

Chapter 2.

BEARING-DISTANCE ~~AZIMUTH-RANGING~~ RADIO-NAVIGATION SYSTEMS.

For the measurement of coordinates and parameters of the motion of aircraft in radio-navigation systems is utilized the communication/connection of the measured value with any parameter of electromagnetic wave - by amplitude, the frequency, phase or propagation time. In this case for determining one coordinate it suffices to utilize only one parameter of wave, and the remaining parameters are not utilized, although they can bear the useful information about the coordinates of object. If we for the measurement of coordinates utilize several parameters of electromagnetic wave, then in one and the same radio-navigation system they can be determined several coordinates of object. Such systems in which is utilized the communication/connection of several parameters of electromagnetic wave with navigational values, are called the combined radio-navigation systems.

The large advantage of these systems in comparison with others is the fact that they make it possible to determine the position of aircraft with the aid of only one radio navigation point by the measurement of distance from aircraft to this point and its azimuth relative to the meridian of the same point.

wide application in our country for the solution of the different problems of the navigation of aircraft obtained uglomernodal'nomernaya system RSBN-2.

§ 2.1. General information about system RSBN-2.

Designation/purpose. The radio engineering system of the short-range navigation of RSBN-2 is the combined uglomernodal'nomernoy system of air navigation and landing under severe weather conditions.

Page 53.

The system provides automatic obtaining on the aircraft of the information about its range and azimuth relative to the point of the arrangement/permutation of ground equipment (Fig. 2.1). On the basis of these data the aircraft equipment makes it possible to solve the following navigational problems:

1) air navigation on any rectilinear route, passing through the ground-based radio navigation point RNT (point of the arrangement/permutation of the ground equipment of system). Flights can be made in the direction of the assigned azimuth α_3 both in the RNT and from it - Fig. 2.1;

2) the driving of aircraft in circular orbit with center into the RNT of any radius r_3, by left or right;

3) air navigation in any rectilinear route, not passing through the RNT;

4) clcud penetraticn in that which was assigned for this aircraft type cf line cf descent;

5) the recovery into any given point cf space and the signaling of the tcrque/moment of approach to this pcirt and of its flight/span;

6) autcmatic and napreryvncye determinaticn aboard of the position of aircraft by means of the indication of the instantaneous values of azimuth α and of range r of aircraft relative to RNT.

Installed equipment provides alsc aircraft landing apprcach, if on the earth/grcurd established/installed tle special landing instrumentation cf system RSBN-2.

Additiorally system makes it possible tc measure on the eartl/grcund of the coordinate (azimuth and range) of all aircraft, equipped with the instrumentation of RSBN-2, and reflect/represents the information atout air situaticn on plan position indicator.

Fig. 2.1. To the explanation of the functions of system the RSBN-2: 1 - the trajectory of the assigned azimuth; 2 - the trajectory of the designated orbit; 3 - the trajectory of the assigned rectilinear route; 4 - the zone of the mark of approach to the given point; 5 - the zone of the mark of the flight/span of the given point.

Key: (1) right; (2) left; (3) on; (4) from.

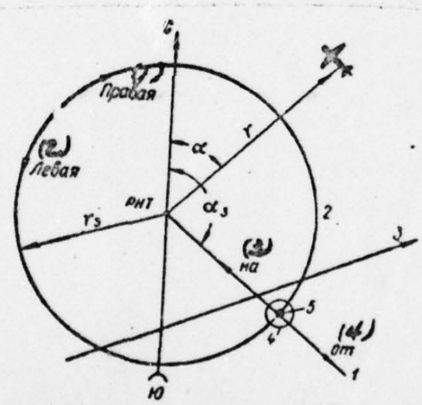


Fig. 2.1

Page 54.

Composition and the interaction of the instrumentation of system.

System RSBN-2 is ground-based and aircraft equipment. According to the character of the solved problems ground equipment can be broken into the navigational and landing.

Navigation equipment is azimuth-ranging radio beacon, it is placed at radio navigation point and consists of the following fundamental sets:

- omnidirectional azimuth radio beacon;
- the relay of range finder;
- plan position indicator IKO;

it consists of monitoring-measuring equipment.

Landing instrumentation is placed at two fixed points near runway and consists of:

- the localizer beacon of KRM-4;
- the glide beacon of GRM-4;
- the landing relay of the range finder, establish/installed in the beacon of GRM-4;

Aircraft equipment is the following equipment:

enter the inquisitor of the range of SZD;

- the aircraft receiver of azimuth and range decay;
- the measuring unit of range BD;
- the measuring unit of the azimuth of BIA;

- the computer SBP, which consists of two separate/individual units - the unit of the administration of BUSBP and unit of the final adjustment of BOSRP;

- the directly indicating instrument of range and azimuth of the navigator of PPDA-W;

- the directly indicating instrument of range and azimuth of the pilot of PPDA-P;

- two combined flight instruments of KII [- flight director] (or NKP-4);

- the control panel of navigator;

- the control panel of pilot.

In addition to this basic equipment, aircraft equipment are several supplementary units (coupling unit with landing system SP-50, the panel of the control of landing etc.). The complete assembly of aircraft equipment weighs about 80 kg.

Page 55.

Aircraft equipment is common/general/total for the solution of navigatical and landing problems. The measurement of the coordinates of aircraft in system RSBN-2 is realized by the exchange of the radio signals between the aircraft and ground equipment (Fig. 2.2).

The azimuth determination and range of aircraft aboard also of the coordinates of aircraft on the earth/ground is realized in the joint operation of azimuth-ranging radio beacon and aircraft equipment. Ranging on aircraft is conducted by means of transmission

from the aircraft of signals to azimuth-ranging radio beacon and their re-emission to aircraft by the relay of range finder. In this case the signal frequencies, which go with aircraft to the relay of range finder and with it to aircraft, are selected different. Aircraft transmitter (SZD) works at frequencies $f_{3д}$, lying at the lower part of the frequency band, occupied by system RSBN-2, and the transmitter of the relay of range finder it works at frequencies $f_{д}$, lying at the upper part of the range (Fig. 2.3). The measurement of azimuth on aircraft is realized by reception and processing aboard of the signals of azimuth radio beacon. The transmitters of this beacon work at frequencies f_{A}, occupying the middle section of the frequency band of the system RSBN-2 (see Fig. 2.3). Coordinate determination of aircraft on the earth/ground is conducted by the consistent use of signals of azimuth radio beacon and signals of the transmitter of the relay of range finder, re-emitted with aircraft equipment.

Fig. 2.2. Interaction of the instrumentation of system RSBN-2.

Key: (1) the relay of range finder; (2) azimuth radio beacon; (3) aircraft equipment; (4) localizer beacon; (5) glide-path beacon.

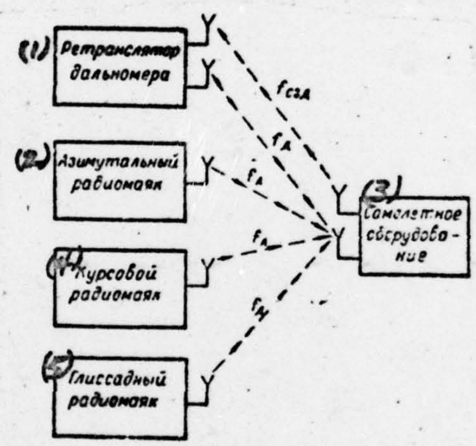


Fig. 2.2

Page 56.

The information about the coordinates of aircraft, equipped with system RSBN-2 and which are located in the zone of action of azimuth-ranging radio beacon, is represented on IKO.

Aircraft landing approach at the signals of the course and glide-path beacons of system RSBN-2 is realized in the joint operation of ground-based landing and aircraft equipment. Localizer beacon transmits to aircraft signals at frequencies, which lie at the same range, as the signals of azimuth radio beacon. Glide-path beacon transmits to aircraft the signals, which occupy the same frequency band, as the signals of the transmitter of the relay of the range finder of azimuth-ranging radio beacon. Simultaneously on the same section of frequency range works the landing relay of the range finder with the aid of which with landing approach is measured the distance from aircraft to GRM.

Fundamental system performances RSBN-2.

1. Frequency band. System works in decimeter frequency band and occupies range from 770 to 970 Mhz. To these frequencies corresponds wavelength from 39 to 31 cm.

2. The range of any system, which works in VHF range, is restricted to line-of-sight distance $r_{\text{пр}}$ between the points of the location of the transmitting antenna at one end/lead of the radio link

and receiving antenna at another end/lead. In the communication/connection between ground equipment and aircraft the line-of-sight distance is determined as follows:

$$r_{\text{пр}} = k\left(\sqrt{h_{\text{а}}} + \sqrt{H}\right), \tag{2.1}$$

where $r_{\text{пр}}$ is a line-of-sight distance, km;

$h_{\text{а}}$ - the height/altitude of the suspension of the ground-based antenna above the middle level of area relief, m;

H - the flight altitude of the aircraft above that level, m;

k - the constant coefficient, which takes different values depending on conditions.

Fig. 2.3. Allocation of frequencies in system the RSBN-2: 1 - frequency band the SZD; 2 - the frequency band of azimuth radio beacon and KRM; 3 - the frequency band of the transmitter of the relay of range finder and GRM.

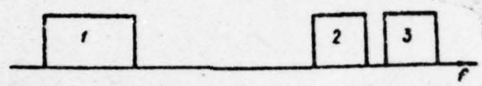


Fig. 2.3

Table 2.1.

H, м	1000	2000	3000	4000	5000	6000	7000	8000	10000	12000
$r_{пр}$, км	117	166	202	234	262	287	310	330	370	406

This coefficient is equal to 3.57 not allowing for atmospheric refraction even 4.12 taking into account normal atmospheric refraction. Upon consideration of the middle conditions of radiowave propagation in practice it is accepted coefficient k to undertake equal to 3.7.

For the target/purpose of the illustration of the possible values of line-of-sight distance table gives the calculated from formula (2.1) values depending on flight altitude under condition $h_a \ll H$ and k = 3.7.

Virtually the range of the systems of VHF [УКВ] range does not reach the values of line-of-sight distance. The range of system RSBN is characterized by the following numerals: 380 km at height/altitude 12000 m, 250 km at height/altitude 5000 m, 50 km at height/altitude 250 m. Relatively short range of system RSBN defines its use as systems of the blizheny of navigation.

3. Accuracy of work. The system RSBN-2 provides the high accuracy of the measurement of the coordinates of aircraft. The dual root-mean-square measuring error of azimuth on aircraft is 0.25°. The dual root-mean-square measuring error of range on aircraft is equal to 200 m + 0.03o/o of r, where r are equal the measured distance. The accuracy of the measurement of the coordinates of aircraft on the earth/ground is characterized by the root-mean-square measuring error of azimuth by 1° and root-mean-square measuring error of range 2.5 km.

4. Capacity. The ranging channel of system RSBN-2 provides the simultaneous measurement of distance on 100 aircraft. If in the zone

of action of azimuth-ranging beacon is located the larger amount of aircraft, then normal work of ranging channel is disrupted and on aircraft there can be the breaks in obtaining the information about range. The capacity of the azimuth channel of neogranichenna.

§ 2.2. Principle of ranging on aircraft.

For ranging on aircraft in system RSBN-2 is utilized pulse ranging system with the relay retort of signals, the common/general/total operating principle of which is examined in chapter 1.

Page 58.

The block diagram of the ranging channel of system RSBN-2 is given in Fig. 2.4, and time diagrams of processes, which elucidate the principle of ranging, in Fig. 2.5.

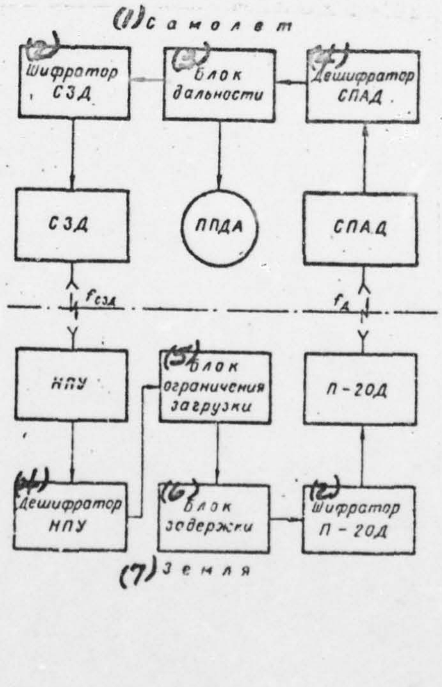
During ranging on aircraft are utilized the inquisitor of the range of SZD, the aircraft receiver of azimuth and range decay and the measuring unit of range BD. On the earth/ground is utilized the relay of range finder, which consists of the transmitter of relay R-200 [redacted] with the transmitting nanapravlennoy of horizontal plane antenna and the ground-based receptor of NPU with the omnidirectional of horizontal plane receiving antenna.

Ranging channel works as follows. In the measuring unit of range are developed the starting video pulses (Fig. 2.5a), the following

with one of the two repetition frequencies: 100 or 30 Hz. Momentum/impulse/pulses enter the encoder of the aircraft transmitter of SZD, where is form/shaped inquiring code (Fig. 2.5b), which is two-pulse interval-time/temporary code.

Fig. 2.4. Block diagram of the ranging channel of system BSBN-2.

Key: (1) aircraft; (2) encoder; (3) range unit; (4) decoder; (5) the unit of the limitation of charging; (6) delay unit; (7) the earth/ground.



Page 59.

The code interval of inquiring signal T_{ks} can accept four different values. Svukhimpul'snyy code from the output/yield of encoder starts the high-frequency oscillator of the transmitter of the SZD, which generates high-frequency two-pulse signal with code interval T_{ks} (Fig. 2.5c). Duration τ_{u} each momentum/impulse/pulse of this signal is 1 µs. Transmitter SZD can work on one of the 10 record/fixed frequencies. For each of these frequencies can be used any of four code intervals T_{ks}. As a result of this SZD it can develop 40 (10 × 4) the different signals, which differ from each other either in terms of carrier frequency or by code interval. Thus is provided work SZD on 40 frequency-code channels.

Fig. 2.5. The time diagrams of the ranging channel of system RSBN-2.

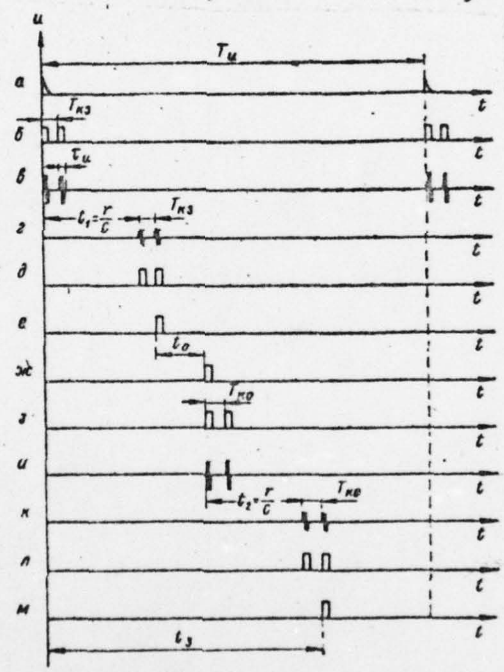


Fig. 2.5

Page 60.

High-frequency signal SZD approaches the omnidirectional in horizontal plane transmitting antenna and is emitted into space. Part of the emitted signal is propagated in the direction of azimuth-ranging beacon. The signal, which is propagated from aircraft to the relay of range finder is called inquiring. On the earth/ground inquiring signal is accepted NPU (Fig. 2.5d). During the propagation of inquiring signal from aircraft to the relay of range finder occurs its time lag to value

$$t_1 = \frac{r}{c}, \quad (2.2)$$

where r - the inclined distance between the aircraft and the relay; c - the velocity of propagation of radio waves.

Therefore on time diagram the adopted on the earth/ground inquiring signal is shifted to the right along the axis of time by value t_1 with respect to the torque/moment of the emission/radiation of this signal on aircraft. In addition to this the received signal differs from that which is emitted in terms of its value. During the emission of the signal in space occurs its considerable attenuation. All the same remaining parameters of the adopted inquiring signal the same as emitted.

The taken inquiring signal is amplified in the receiver of the

NPU which is tuned to a frequency of inquiring signal $f_{\text{зап}}$ and is detected. At the output/yield of detector is separate/liberated two-pulse inquiring code with code interval $T_{\text{з}}$ (Fig. 2.5e), which is supplied to the decoder of the receiver of NPU. Decoder realizes a decoding of inquiring signal (Fig. 2.6a). The process of decoding can be explained with the aid of Fig. 2.6a, on which is depicted the simplified block diagram of decoder.

Decoder is the delay line, which realizes a signal delay in time of the value, equal to code interval $T_{\text{з}}$ inquiring signal. To the inlet of this line are supplied the signals from the output/yield of the detector of receiver. Momentum/impulse/pulses in the output/yield of delay line approach coincidence circuit. There are supplied momentum/impulse/pulses in the inlet of delay line. If the code interval of the entering the decoder signal is equal to the delay time in the line, then at the onset of the second momentum/impulse/pulse of code at two inlets of coincidence circuit momentum/impulse/pulses coincide in time and it gating pulse on output/yield (Fig. 2.6b). But if the code interval of the signal, which enters the decoder, is not equal to the delay time in the line, then not at which point in time on it occurs pulse coincidence and at the output/yield of coincidence circuit the signal is not separate/liberated (Fig. 2.6c).

Page 61.

Thus, during correct installation in the decoder of code interval, at its output/yield is separate/liberated the momentum/impulse/pulse,

which coincides with the last/latter momentum/impulse/pulse of inquiring code (Fig. 2.5f). In decoder can be established/installed 4 values of delay time, equal to the code intervals of inquiring signal.

Receiver NPU is tuned for 10 record/fixed frequencies, equal to the frequencies of inquiring signal. By means of selection of one of the 10 frequencies even one of the four values of code interval receiver NPU can be inclined on any of 40 frequency-code channels of system.

[redacted]

[redacted]

[redacted]

Page 61 cont.

Momentum/impulse/pulse from the output/yield of the decoder through the unit of the limitation of charging and the delay line whose designation/purpose will be clarified it approaches below the encoder of the transmitter of P-20D. Delay line delays momentum/impulse/pulses for a period t_0, which leads to signal lag at the inlet of encoder (Fig. 2.5g) with respect to momentum/impulse/pulses at the output/yield of decoder on value t_0.

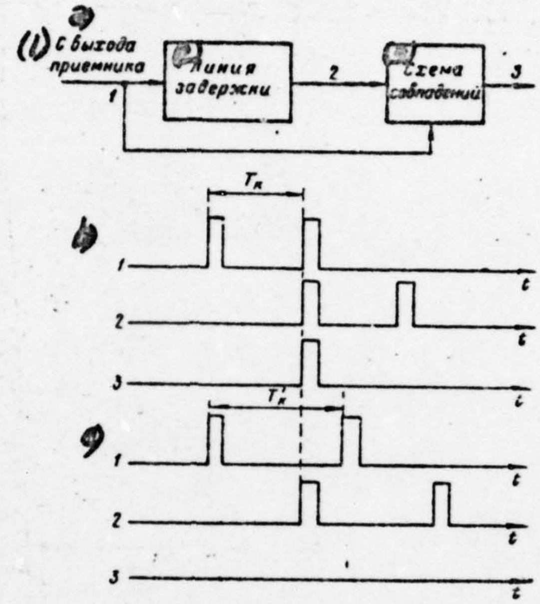


Fig. 2.6. To the explanation of the process of the decoding: a) the block diagram of decoder; b and c) time diagrams; 1 - momentum/impulse/pulses at the inlet of decoder; 2 - momentum/impulse/pulses at the output/yield of delay line; 3 - momentum/impulse/pulses at the output/yield of decoder.

Key: (1) in the output/yield of receiver; (2) delay line; (3) coincidence circuit.

Page 62.

The encoder of the transmitter of P-20D develops reciprocal code (fig. 2.5h), which just as inquiring, is two-pulse interval-time/temporary code, but with another code interval $T_{\text{ко}}$. Reciprocal code approaches the high-frequency oscillator of the transmitter of the P-20D, which generates two-pulse high-frequency signal (Fig. 2.5 l).

Transmitter P-20D works at 40 different record/fixed frequencies, so that for each frequency-code channel of system is utilized its frequency.

The high-frequency signal of the transmitter of P-20D enters the transmitting antenna, it is emitted into space and is propagated in opposite direction to aircraft. This signal is called reciprocal. During the propagation of response signal from the relay of range finder to aircraft occurs its time lag to value

$$t_2 = \frac{r}{c}. \quad (2.3).$$

The come to aircraft response signal (Fig. 2.5j) is received as the omnidirectional in horizontal plane receiving antenna and enters receiver the decay where it is amplified and is detected (Fig. 2.5k). Reciprocal code from the output/yield of detector is supplied to the decoder of receiver decay. Decoder decodes reciprocal code analogous with that, as this was described above for a ground-based decoder.

Momentum/impulse/pulse from the output/yield of the decoder of receiver the decay (Fig. 2.51), called reciprocal momentum/impulse/pulse, approaches the measuring unit of range.

Reciprocal momentum/impulse/pulse (Fig. 2.5) it delays with respect to trigger pulse in each repetition period for a period:

$$t_3 = t_1 + t_2 + t_0 + T_{K3} + T_{K0}. \tag{2.4}$$

Taking into account of expression (2.2) and (2.3), equation (2.4) can be rewritten as follows:

$$t_3 = \frac{2r}{c} + t_0 + T_{K3} + T_0. \tag{2.5}$$

The last/latter equation shows that the time lag of reciprocal momentum/impulse/pulse is equal to the sum of two time intervals. The first of them,

$$t_{3r} = \frac{2r}{c}, \tag{2.6}$$

directly proportional to inclined distance from aircraft to azimuth-ranging beacon.

Page 63.

The second interval $\tau=t_0+T_{\text{кз}}+T_{\text{ко}}$, determined by delay time on the earth/ground and by the code intervals of inquiring and response signals, is constant and does not depend on range. Therefore the time lag of reciprocal momentum/impulse/pulse t_3 unambiguously is determined by the distance between the aircraft RNT. By the measurement of time lag can be determined range from aircraft to the point of the arrangement/permutation of ground equipment.

The measurement of the time lag of reciprocal momentum/impulse/pulse realizes a measuring unit of range. Works of unit it occurs automatically and continuously. The measured range transmits to the instruments of PPDA. These instruments continuously indicate to aircrew the current slant range from aircraft to the relay of range finder. The range scale of instruments PPDA is executed in the form of drum type counters. The value one scale division of range is 0.1 km.

For ranging in the measuring unit of range is applied the two-scale method of the measurement because of which is reached the high accuracy of measurement. ED it works in two mode/conditions - search and trackings. First after the start of instrumentation is utilized search mode. In this mode/conditions the range is measured roughly, with an accuracy to 10 km, i.e. is determined that desyatikilometrovyy section of range N, in limits of which is located the aircraft. After this automatically is included the mode/conditions of the tracking in which with high accuracy is measured the position of aircraft r_x (Fig. 2.7) within the obtained

in search mode for desyatikilcmetrovogo section. The measured distance r is defined as sum of the readings, obtained of the search modes and tracking:

$$r=10(N-1)+r_{s}. \tag{2.7}$$

Fig. 2.7. To the explanation of the double-dial method of ranging.

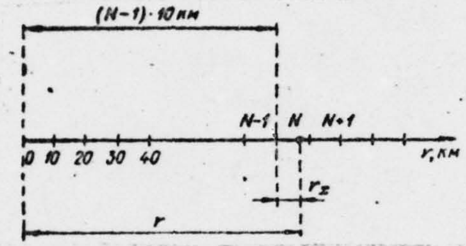


Fig. 2.7

Page 64.

The ranging circuit in BD can measure the time lag of reciprocal momentum/impulse/pulse, beginning with certain minimum interval t_{3min}. The normal measurement of distance is provided at all ranges for which delay time $t_0 > t_{3min}$. For the possibility of the measurement of zero ranges it is necessary that the time lag with r = 0 be also more than value t_{3min}, i.e.

$$\tau = t_0 + T_{\kappa.3} + T_{\kappa.o} > t_{3min}. \quad (2.8)$$

For the target/purpose of the provision for satisfaction of this condition on the earth/ground in the relay of range finder is utilized the line of a signal delay for a period $t_0 \approx 130$ µs. General initial delay taking into account code intervals is approximately 180 µs.

The process of obtaining the information described above about range before azimuth-ranging beacon is realized aboard of each aircraft, which is located in the zone of action of this beacon and which has the connected on the necessary channel equipment RSBN [- Short-range Navigation Radio System]. In this case the relay of range finder must answer the inquiring signals of all aircraft. Therefore the repetition frequency of the response signals of relay is equal to:

(2.9) $$F_{отв} = nF_{u},$$

where n is equal the amount of aircraft with the working equipment RSBN in the zone of action of beacon;

F_{u} - the repetition frequency of the interrogation signals of one aircraft.

With an increase in the amount of aircraft the increasing frequency of response signals and with the determined number n it can become the so large that the transmitter P-20D is overloaded, it ceases normally to work and even it can leave the system in connection with an increase in developed average power. For this prevention in the relay of range finder is a unit of the limitation of charging. This unit works as follows. When in the zone of action of beacon it is located less than 100 aircraft, then it transmits all the inquiring signals, which enter it, so that relay answers the demands of all aircraft and aboard of each aircraft normally is measured omnidistance. But if relay requests itself more than one hundred by aircraft, then the unit of the limitation of charging is cut off to the determined time intervals and part of the inquiring signals to transmitter P-20D does not enter. The more the aircraft it requests relay, by the fact to the large intervals is closed the unit of the limitation of charging and the larger amount of inquiring signals it is screened. The pulse repetition frequency at the output/yield of the unit of the limitation of charging in this case is supported by

constant at the level of the allowed value $F_{отв.доп} = 100 F_v$.

Page 65.

As a result of the fact that the relay of range finder develops response signals not to all inquiring signals with n > 100, the repetition frequency of the response signals, which come in to each aircraft, decreases and this it leads to the disturbance of the measuring unit of range. For the indicated reason the capacity of the ranging channel of system RSBN is restricted to 100 aircraft.

§ 2.3. Process of automatic ranging on aircraft.

In work of the ranging channel of system RSBN aboard the aircraft in the measuring unit of range is realized the automatic measurement of the time lag of reciprocal momentum/impulse/pulse. Let us examine work of this unit (Fig. 2.8).

For the measurement of the time lag of reciprocal momentum/impulse/pulse, and it means distances of ground beacon, in BD is utilized the method of comparison of this time with the standard time interval as which it is undertaken the period of the stabilized by quartz sine voltage.

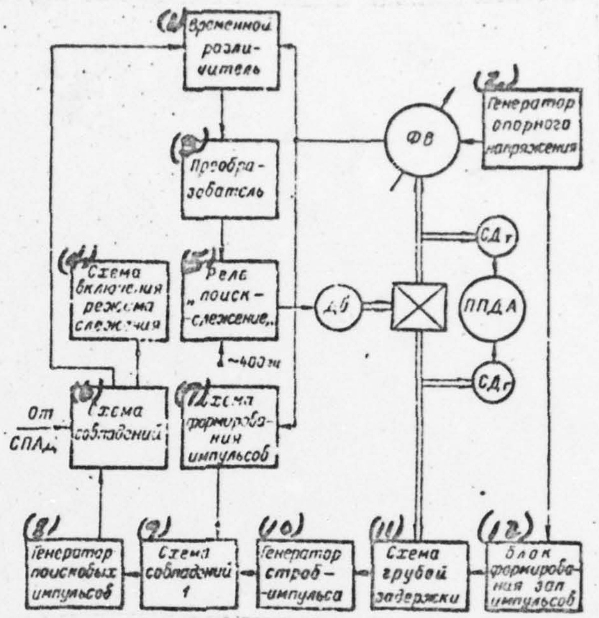


Fig. 2.8. Functional diagram of range unit.

Key: (1) time/temporary discriminator; (2) reference generator; (3) converter; (4) the circuit diagram of the mode/conditions of tracking; (5) relays "search-tracking"; (6) the diagram of sobpadeniy; (7) the pulse-shaping circuit; (8) the generator of search momentum/impulse/pulses; (9) coincidence circuit; (10) gate generator; (11) the diagram of rough delay; (12) shaping unit western momentum/impulse/pulses.

Page 66.

This voltage (Fig. 2.9a) it is developed by reference generator. Frequency of reference voltage F ≈ 15 kHz, and period T ≈ 66.7 μs. This value of the period of reference voltage corresponds to distance 10 km in accordance with the krown dependence of the time lag and distance in ranging systems with the relay retort of signals $t = 2r/c$. Reference voltage enters the shaping unit of trigger pulses. Here from sine voltage they are form/shaped momentum/impulse/pulses (Fig. 2.9b) each time when reference voltage reaches zero value during its change from negative values to positive. The ASTOTA of the repetition of these momentum/impulse/pulses is accurately equal to the frequency of reference voltage.

Then from momentum/impulse/pulses 15 kHz frequency are developed trigger pulses with repetition frequency 100 Hz either 30 Hz by frequency division into 150 or 500 times. Trigger pulses (Fig. 2.9c) are connected with the fixed point of reference voltage. They approach SZD and to the diagram of rough delay.

The diagram of rough delay wear/operates at the torque/moment of the admission on it of trigger pulse and form/shapes square pulse (Fig. 2.9d). The duration of this momentum/impulse/pulse depends on the angle of rotation of the axis, which connects engine with the diagram of rough delay, and it can vary from 140 μs (t_{3min}) to 3140 μs. The range of a change in the duration of this momentum/impulse/pulse 3000 μs corresponds to distance 450 km. By

the trailing edge of pulse of the diagram of rough delay is started gate generator. This generator form/shapes rectangular gate pulse (Fig. 2.9e) whose beginning coincides with the trailing edge of pulse of the diagram of rough delay, and duration is equal to 60 μs, that somewhat less than the period of reference voltage. During the rotation/revolution of engine will change the pulse duration of the diagram of rough delay and consequently, gate pulse it will be moved along time/temporary axis within limits from 140 to 3140 μs or according to the scale of range from 0 to 450 km.

Engine is connected also through the reducer with the phase inverter which is utilized as the device of a precise delay. To phase inverter is supplied the reference voltage from reference generator. From phase inverter is remove/taken the sine voltage of the same frequency, as supporting/reference, but shifted relative to it on phase by the angle, equal to the angle of rotation of the rotor of phase inverter.

Page 67.

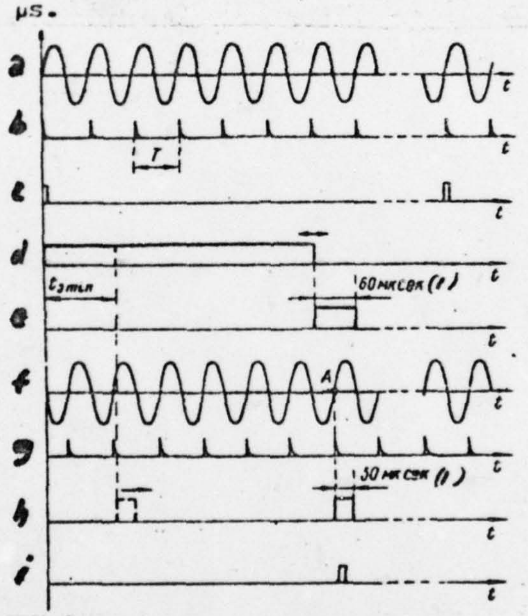
Out of phase reference voltage (Fig. 2.9f) it is supplied to the pulse-shaping circuit. This diagram form/shapes momentum/impulse/pulses (Fig. 2.9g) at the torque/moment of equality to zero out of phase of reference voltage during its change from negative values to positive.

During the rotation/revolution of phase inverter changes the phase of voltage on its output/yield, which corresponds to the bias of

this voltage along time axis. one complete revolution of phase inverter leads to a change in the phase to 360° and to the shift of sine voltage over time/temporary axis is accurate for period of T. Since period of T corresponds to distance 10 km, means to this value it corresponds one complete revolution of phase inverter, and each degree of the angle of rotation of phase inverter it corresponds to distance 28 m. Thus, the angle of rotation of phase inverter φ by the determined shape is connected with distance. The momentum/impulse/pulses, formed from out of phase reference voltage, will be shift/sheared along time/temporary axis together with sine voltage.

Fig. 2.9. The time diagrams of range unit.

Key: (1) μs.



Page 68.

These momentum/impulse/pulses are supplied to coincidence circuit 1, where also enters gate pulse. With the aid of gate pulse the coincidence circuit separate/liberates the only one momentum/impulse/pulse, formed of out of phase reference voltage, that that coincides with gate pulse. The chosen momentum/impulse/pulse approaches the generator of search momentum/impulse/pulses, which form/shapes the momentum/impulse/pulse of search (Fig. 2.9h) by duration 30 μs.

The momentum/impulse/pulse of search is moved during the rotation/revolution of engine along time/temporary axis (range scale). The position of the momentum/impulse/pulse of search on time/temporary axis is determined simultaneously by the angle of rotation of the axis, connected with the diagram of rough delay (rough axis), and the axis, which goes to phase inverter (precise axis). Rough and precise axis are connected through the reducer with relationship 1: 25, i.e., one turn of rough axis leads to 25 turns of a precise axis. Because of this stiffening joint of rough and precise axes, one turn of phase inverter corresponds a change in the pulse duration of the diagram of rough delay approximately of the period of reference voltage (10 km according to the scale of range). Therefore gate pulse is connected with one and the same period out of phase of reference voltage, but search momentum/impulse/pulse - with one and the same the point of this stress. Thus, the momentum/impulse/pulse of search during the

rotation/revolution of engine is moved according to an entire range scale, but its position on time/temporary axis is stabilized by reference voltage and accurately is determined by the angle of rotation of phase inverter. After acquaintance with the designation/purpose of the described cell/elements it is possible to pass to the examination of work of the measuring unit of range.

Search mode. Upon start BD first is utilized the search mode. In this mode/conditions in engine with the aid of relay the search-tracking from grid/network is supplied the voltage of frequency 400 Hz. Engine begins to rotate, and the momentum/impulse/pulse of search is moved according to the scale of range. In this case at the determined moment of momentum of search unavoidably will initiate to coincide with the reciprocal momentum/impulse/pulse (Fig. 2.9i), which enters from receiver decay. As a result now at the output/yield of coincidence circuit 2 will bydelya''sya reciprocal momentum/impulse/pulse. This momentum/impulse/pulse approaches the circuit diagram of the mode/conditions of tracking, which is the calculating-memory cascade/stage.

Engine rotates at this velocity by which the shift of the momentum/impulse/pulse of search on entire range scale occurs in 20 s, i.e., the speed of the shift of this momentum/impulse/pulse it comprises:

$$3000\ мксек/20\ сек = 150\ \mu s/s.$$

Inquiring signals in search mode follow with frequency 100 Hz (100 momentum/impulse/pulses per second).

Page 69.

Therefore during the operating cycle of ranging channel the momentum/impulse/pulse of search is moved to interval 1.5 μs . The duration of search momentum/impulse/pulse is 30 μs , and it will coincide with reciprocal momentum/impulse/pulse, in spite of its shift over time/temporary axis, during 20 operating cycles of ranging channel. If to each demand comes response signal, then at the output/yield of coincidence circuit 2 it will be isolated 20 reciprocal momentum/impulse/pulses. Schetrozapominayushchiy cascade/stage produces the calculation of the entering on it reciprocal momentum/impulse/pulses and after the arrival on it of 10-12 momentum/impulse/pulses cascade/stage develops the voltage, which moves relay search - tracking at another position. Line voltage 400 Hz is disconnected from engine, and it ostanavliyetsya, but the momentum/impulse/pulse of search occupies this position on time/temporary axis, by which it coincides with reciprocal momentum/impulse/pulse. On this search mode it concludes.

Thus, in search mode is provided the rough pulse coincidence of search and reciprocal momentum/impulse/pulse and rough ranging with an accuracy to the period of reference voltage (10 km), i.e., is determined that desyatikilometrovyy section of range, in limits of which is located the aircraft. The determination of this section of

range is conducted by calculating the complete revolutions of phase inverter with the aid of the angle of rotation of rough axis.

To each aircraft, except their response signals, caused by the inquiring signals of this aircraft, enter also the response signals, caused by the demands of other aircraft. For correct ranging it is necessary that the measuring unit of range would not react to strange response signals, but correctly found its response signal. The necessary interference shielding of search mode is realized by a diagram of the sklyucheniya of the mode/conditions of tracking. The process of isolation described above by search momentum/impulse/pulse sufficient large number of reciprocal momentum/impulse/pulses is valid only for its response signals, since they come in each operating cycle of ranging channel simultaneously with respect to trigger pulse. The pulse repetition frequencies of different aircraft differ somewhat from each other. Therefore strange response signals approach this aircraft in each operating cycle into the different points in time of the relatively trigger pulses and the momentum/impulse/pulse of search it will isolate the small amount of reciprocal momentum/impulse/pulses, with which the calculating-memory cascade/stage will not actuate/operate and will not include/connect the mode/conditions of tracking. The momentum/impulse/pulse of search will not stop at the torque/moment of the arrival of strange reciprocal momentum/impulse/pulses, but it will continue to move over time/temporary axis until it initiates to coincide with its reciprocal momentum/impulse/pulses.

Page 70.

Mode/conditions of tracking. In this mode/conditions works the servo system, which switches on engine, time/temporary discriminator and converter. To engine enters the control voltage, developed by time/temporary discriminator and converter. Frequency by inspector. The repetition frequency of interrogation pulses in the mode/conditions of tracking decreases to 30 Hz.

To time/temporary discriminator enter reciprocal momentum/impulse/pulses from coincidence circuit 2 and out of phase reference voltage from fazovrayaatelya (Fig. 2.10). Time/temporary discriminator develops direct/constant voltage, directly proportional to temporary displacement Δt between the middle of reciprocal momentum/impulse/pulse and the zero point out of phase of reference voltage (this point is marked in Fig. 2.9¢ by letter A:

$$U=K\cdot\Delta t, \tag{2.10}$$

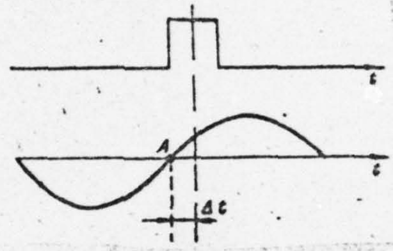
where K - proportionality factor.

During a change in the side of the disagreement/mismatch between reciprocal momentum/impulse/pulse and reference voltage changes the polarity of output potential of time/temporary discriminator.

The output voltage of the time/temporary discriminator U approaches the converter in which is developed the control voltage of frequency 400 Hz. In this case the amplitude of control voltage is

proportional to the constant value stress U, and phase changes by 180° during a change in the polarity of stress U. Under the effect of control voltage the engine is turned to this side, determined by the phase of the control voltage, by which the time/temporary disagreement/mismatch between reciprocal momentum/impulse/pulse and out of phase reference voltage decreases. When time/temporary disagreement/mismatch Δt becomes equal to zero, engine is stopped, since to zero in this case will be equal the amplitude of control voltage. This state of the equilibrium of servo system is stable, since during a change in the time/temporary disagreement/mismatch engine so turns phase inverter, that the time/temporary disagreement/mismatch Δt vanishes. Thus, as a result of work of the mode/conditions of tracking zero point A cut . phase of reference voltage always coincides with the middle of reciprocal momentum/impulse/pulse, i.e., diagram follows the position of response signal.

Fig. 2.10. The time diagrams, which elucidate work of time/temporary discriminator.



Page 71.

This means that the angle of rotation of the rotor of phase inverter accurately determines the measured sstoyaniye.

If in the mode/conditions of tracking for any reason disappeared reciprocal momentum/impulse/pulses for a period, greater than 5 s, then occurs reconnection to search mode and the process of the determination of its response signal is repeated.

In the mode/conditions of tracking is connected the diagram of the reading of range. This diagram consists of the rough and fine selsyns of the sensors, connected with rough and precise measuring axes respectively. These selsyns are connected electrically with selsyns with receivers, which are located in the instruments of PPDA. Receiving synchros are connected in turn, with drum type counter. From the angle of rotation of rough axis is determined the integer of the complete revolutions of phase inverter, i.e., integer N - 1 complete dozen kilometers, which are placed in the measured distance r. The precise measuring axis determines accurately the angle of rotation of phase inverter within the limits of the last/latter incomplete turn. From a precise measuring axis is determined with high accuracy the position of aircraft within the desyatikilometrovogo section of range. If during ranging the phase inverter of povernulyasya on N - 1 complete revolutions it is additional to angle φ, then the measured distance

(2.11). $$r=\left(N-1+\frac{\varphi}{360^\circ}\right)10\ km.$$

In accordance with expression (2.11) the instruments of PPDA take a reading of range. Because of use in the measuring unit of the range of the two-scale method of reading, the range is measured unambiguously, also, with high accuracy.

~~MT/ST-76-659~~

~~jm90~~

~~SUBJECT CODE E214~~

Pages 71-100.

§ 2.4. Principle of the measurement of azimuth on aircraft.

For the measurement of azimuth on aircraft in system RSBN [PCБН - Short-range Navigation Radio System] on the earth/ground is utilized omnidirectional azimuth radio beacon, and on aircraft it is utilized receiver decay, the measuring unit of the azimuth of BIA and the instruments of PPDA. The block diagram of the azimuth channel of system is given in Fig. 2.11.

Azimuth beacon are two transmitter - the transmitter of azimuth signals P-200M and the transmitter of reference signals P-20A.

Page 72.

Transmitter P-20CM works on the directional in horizontal plane azimuth antenna, while transmitter P-20A - ranenapravlennuyu in horizontal plane antenna.

Fig. 2.11. Block diagram of the azimuth channel of system RSBN-2.

Key: (1) reference signals. (2) azim signal.

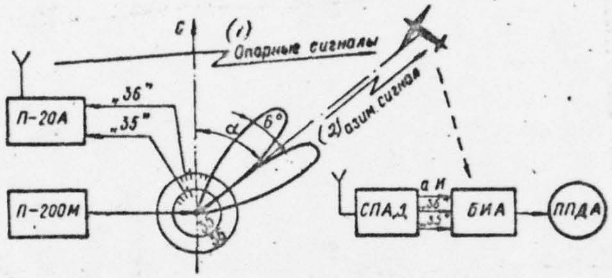


Fig. azimuth channel of system RSBN-2.

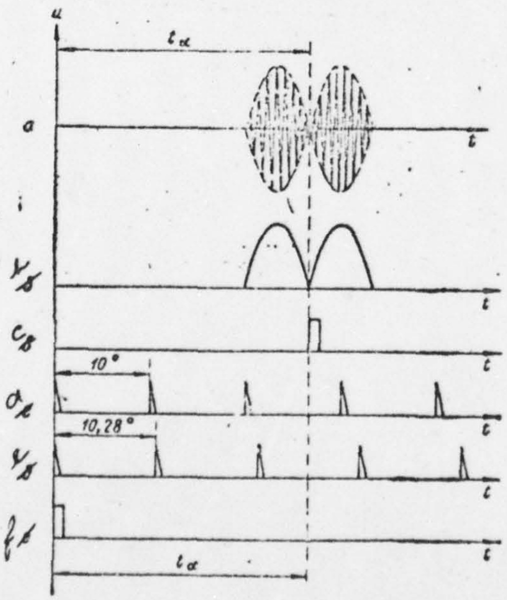


Fig. 2.12. The time diagrams of the azimuth channel of system RSBN-2.

Azimuth antenna has in horizontal plane a radiation pattern in the form of two narrow being contacted lug/lobes. The width of each lug/lobe is 6°.

Page 73.

Azimuth antenna rotates in horizontal plane at constant velocity n = 100 r/min. Transmitter P-200M develops the continuous high-frequency unmodulated oscillations at the frequency of azimuth channel f_A. However, since the azimuth antenna is directed, then the signals, emitted as it, are accepted on aircraft not always, but only if azimuth antenna is oriented toward aircraft. The signal of azimuth antenna is received on aircraft as receiver decay and is called azimuth signal. It (Fig. 2.12a) it is the high-frequency signal whose envelope shape is determined by the form of the radiation pattern of azimuth antenna. The point in time, kgoda going around azimuth signal reaches zero between two maximums, it corresponds to that point in time when the axis of azimuth antenna is accurately directed toward aircraft or, in other words, to that torque/moment when the angle of rotation of azimuth antenna became accurately was equal to the azimuth of aircraft α. Time interval t_d for which azimuth antenna turned itself to angle α, directly proportional to the azimuth of aircraft as a result of the constancy of the rotational speed of the azimuth antenna:

(2.12) $$t_a = \frac{T_{sp}}{360^\circ} \alpha$$

or

(2.13) $$\alpha = \frac{360^\circ}{T_{sp}} t_a.$$

where $T_{sp} = \frac{60}{n'} = 0{,}6$ s - time of one complete revolution of azimuth antenna.

Therefore time interval t_a can serve as the measure of the azimuth of aircraft and for determining azimuth is conducted the measurement of the time lag of azimuth signal with respect to the torque/moment of passage by the azimuth antenna of northern direction (origin of coordinates in time diagrams, Fig. 2.12).

Azimuth signal is amplified by receiver decay and is detected by it (Fig. 2.12b). Then at the torque/moment of achievement that which go around the zero value between two maximums is form/shaped azimuth momentum/impulse/pulse (Fig. 2.12c), which enters BIA and is utilized for the measurement of azimuth.

Azimuth momentum/impulse/pulse can be used for determining azimuth by the measurement of the time lag of azimuth momentum/impulse/pulse t_a if on aircraft will be fixed point in time when azimuth antenna is directed toward north. The information about this point in time transmits to aircraft with the aid of reference signals.

Page 74.

Reference signals are form/shaped with the transmitter of P-20A as follows. On the axis of the rotation/revolution of azimuth antenna are established/installed two rings with contacts. On one ring evenly in circumference are placed 36 contacts, while on another 35. Each ring is connected with the transmitter of reference signals with the aid of slip ring. During the rotation/revolution of azimuth antenna in slip rings are excited the momentum/impulse/pulses every time that past the slip ring it passes contact. The momentum/impulse/pulses, removed from ring with 36 contacts, are called "supporting/reference 36", and removed from ring with 35 contacts - "supporting/reference 35".

Reference pulses "36" (Fig. 2.12d) represent sequence of 36 momentum/impulse/pulses in one turn of the antenna, following each other through angular interval of 10°. Disk with 36 contacts is oriented on the axis of the rotation/revolution of azimuth antenna so that one of the momentum/impulse/pulses "36" appears at the torque/moment of passage by the azimuth antenna of northern direction.

Reference pulses "35" (Fig. 2.12e) represent sequence of 35 momentum/impulse/pulses in one turn of the antenna, following each other through angular interval of 10.28°. Ring with 35 contacts it is oriented on the axis of rotation/revolution in such a way that one of the momentum/impulse/pulses "35" appears at the torque/moment of passage by the azimuth antenna of northern direction. This

momentum/impulse/pulse, thus, ccincides with the appropriate momentum/impulse/pulse from sequence "36". All the same remaining momentum/impulse/pulses cf sequence "35" in cne turn of antenna do not coincide with reference pulses "36". After each complete revclution of the azimuth antenna when it is turned accurately to north, again occurs the agreement of one mcmentum/impulse/pulse "35" with one momentum/impulse/pulse "36". Reference pulses are converted in the transmitter cf P-20A into reference signals. During the admission of each reference pulse "36" the transmitter P-20A generates the two-pulse high-frequency coded signal with the code interval T_{36}. Reference pulses "35" also are converted by the transmitter cf reference signals into two-pulse high-frequency signal, but with another code interval T_{35}. The duration of each high-frequency pulse is 6 μss. Reference signals are emitted by the omnidirectional in horizontal plane antenna immediately to all aircraft and are received as receiver decay. In receiver the reference signals are amplified, are detected and then are decoded. After decoding at different output/yields are separate/liberated the reference pulses "36" and "35" (Fig. 2.12d and e) and are supplied to EIA. Reference signals transmit at the same carrier frequency f_A as azimuth signals. The separation of reference and azimuth signals in receiver is possible because cf the different duration cf these signals.

Page 75.

The width of azimuth signal in angular unity is 12°. The duration of

this signal in accordance with equation (2.12) $\tau_A = \frac{12°}{360°} T_{np} = 0{,}02$ s, i.e., is considerably more the duration of reference signals. Azimuth signal is passed in the receiver through the integrating circuit with this time constant, past which the reference signals do not pass.

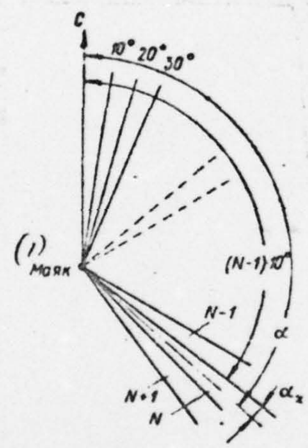
In the measuring unit of azimuth the reference pulses "36" and "35" are utilized for determining point in time when azimuth antenna is oriented toward north. For this at torque/moment pulse coincidence from sequence "36" with one momentum/impulse/pulse of sequence "35" are developed the momentum/impulse/pulses of northern agreement (Fig. 2.12f), which record/fix the reference point of azimuth (northern direction of azimuth antenna). Now with known reference point can be measured the time interval between the momentum/impulse/pulse of northern agreement and azimuth momentum/impulse/pulse and is determined the azimuth of aircraft.

The measurement of time interval t_a is realized BIA automatically and is continuous with the ispol'zvaniyem of all reference pulses "36" and "35" as standard angular grid. The measured azimuth of aircraft transmits to the instruments of the PPDA, which continuously indicate to aircrew the current azimuth relative to the point of the arrangement/permutation of azimuth-ranging beacon. The azimuth scale of instruments PPDA is executed in the form of needle indicator. Navigator's instrument provides the more fine reading of azimuth. The value one scale divisions of the azimuth of PPDA-N composes 0.1°, and the instrument of PPDA-P 2°. For the measurement of azimuth into BIA is applied the two-scale method of the measurement because of which is reached high accuracy. Bia works in two

mode/conditicns - search and trackings. First after the start of instrumentation is utilized search mode. In this mode/conditiors the azimuth is measured roughly, with an accuracy tc 10°, i.e., is determined that desyatigradusnyy sector N of the space, in limits of which is located the aircraft.

Fig. 2.13. To the explanation of the two-scale method of the measurement of azimuth.

Key: (1) beacon.



Page 76.

After this automatically is included the mode/conditions of the tracking in which with high accuracy is measured the position of aircraft α_x (Fig. 2.13) within the obtained in search mode for desyatigradusnogo sector. The measured azimuth α is defined as sum of the readings, obtained of the search modes and tracking:

(2.14). $\alpha = 10(N-1)+\alpha_x.$

As it follows from the principles of ranging and azimuth on aircraft, all signals of ranging and azimuth channels are accepted and they are separate/liberated at different output/yields one and the same receiver decay. For the clearer understanding of the operating principles of system RSBN let us examine block diagram (Fig. 2.14) and work of receiver decay.

Fig. 2.14. Block diagram of receiver decay.

Key: (1) DSh response signal. (2) on . (3) DSh zaprashitayushchego signal. (4) the diagram of the isolation of interrogation pulse. (5) the shaping unit of azimuth momentum/impulse/pulse. (6) DSh reference signals. (7) the unit of landing.

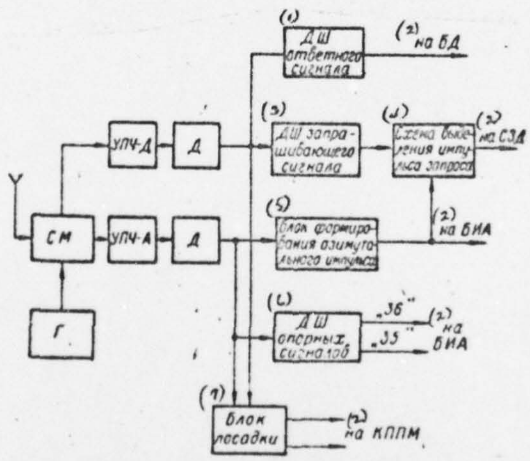


Fig. 2.14

This receiver is diplex superheterodyne radio receiver. Out of antenna the signals of the relay of range finder with carrier frequency $f_Д$ and the signals of azimuth beacon with carrier frequency f_A approach common/general/total mixer. There is supplied the voltage of the heterodyne which can work at 40 different frequencies $f_Г$, providing thereby 40 frequency channels of system. At the output/yield of mixer are separate/liberated the signals of two different intermediate frequencies - $f_{пр.Д}$ for a ranging channel and for an azimuth channel.

(2.15). $$f_{пр.Д} = f_Д - f_Г; \quad f_{пр.А} = f_А - f_Г.$$

Page 77.

The intermediate frequencies are constants; therefore and their difference $f_{пр.Д} - f_{пр.А}$ also a constant value. From equations (2.15) it is evident that a difference in frequencies of the ranging and azimuth channels also must be the constant value:

(2.16). $$f_Д - f_А = f_{пр.Д} - f_{пр.А} = \text{const}.$$

This means that the simultaneous reception of the signals of ranging and azimuth channels is feasible only in such a case, when a

difference in frequencies $f_{Д}$ and f_A is one and the same, independent of the utilized frequency-code channel. For this reason during switching the channels of frequency $f_{Д}$ and f_A they must change by one and the same value.

From the output/yield of mixer the signals of frequency $f_{пр.Д}$ dostupayut to the IF amplifier of the ranging channel of UPC-D, they are amplified by it and are detected. After detector the response signals of the relay of range finder are decoded in the decoder of response signals and the chosen at its output/yield reciprocal momentum/impulse/pulse it approaches the measuring unit of range.

The decoder of inquiring signals and the diagram of the isolation of interrogation pulses, connected with UPC-D, are utilized during coordinate determination of aircraft on the earth/ground and will be examined below.

The signals of frequency $f_{пр.А}$ from the output/yield of mixer are supplied to the IF amplifier of the azimuth channel of UPC-A, they are amplified by it and are detected. At the output/yield of the detector of the azimuth channel of receiver the decay is separate/liberated azimuth signal and reference signals. Azimuth signal it passes on the shaping unit of the azimuth momentum/impulse/pulse which develops the azimuth momentum/impulse/pulse, which enters the measuring unit of azimuth. Reference signals pass to the decoder of reference signals in which the signals "36" and "35" separately decoded because of the different code intervals T_{36} and T_{35}. As a result at the output/yield of this decoder are separate/liberated at different output/yields the reference pulses "36" and "35", which enter EIA. In work of

instrumentation in landing mode/conditions at the output/yield of UPC-D are separate/liberated the signals of glide beacon, and at the output/yield of UPC-A are separate/liberated the signals of radio range beacon. These signals approach the special unit of landing.

§ 2.5. Process of the automatic measurement of azimuth on aircraft.

In work of the azimuth channel of system BSEN aboard the aircraft in the measuring unit of azimuth is conducted the automatic measurement of azimuth with high accuracy. Let us examine work BIA (Fig. 2.15).

Page 78.

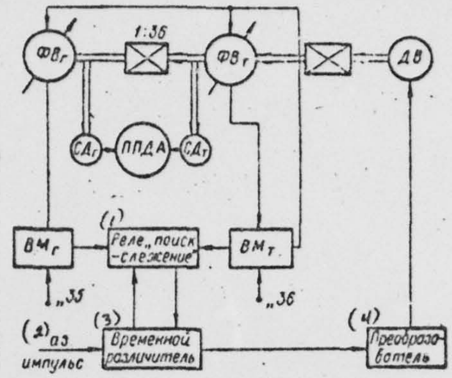


Fig. 2.15. Functional diagram of the measuring unit of azimuth.

Key: (1) relays "poiskslezheniye". (2) az momentum/impulse/pulse. (3) time/temporary discriminator. (4) Preobrazovotel'.

To BIA from receiver decay enter the following signals:

enter azimuth momentum/impulse/pulses with repetition frequency

Hz; $$F_A = \frac{1}{T_{вр}} \approx 1{,}7\ [\text{гц} = \text{Hz}]$$

- the sequence of reference pulses "36" with repetition frequency:

Hz $$F_{36} = \frac{36}{T_{вр}} = 60\ [\text{гц} = \text{Hz}]$$

- the sequence of reference pulses "35" with repetition frequency:

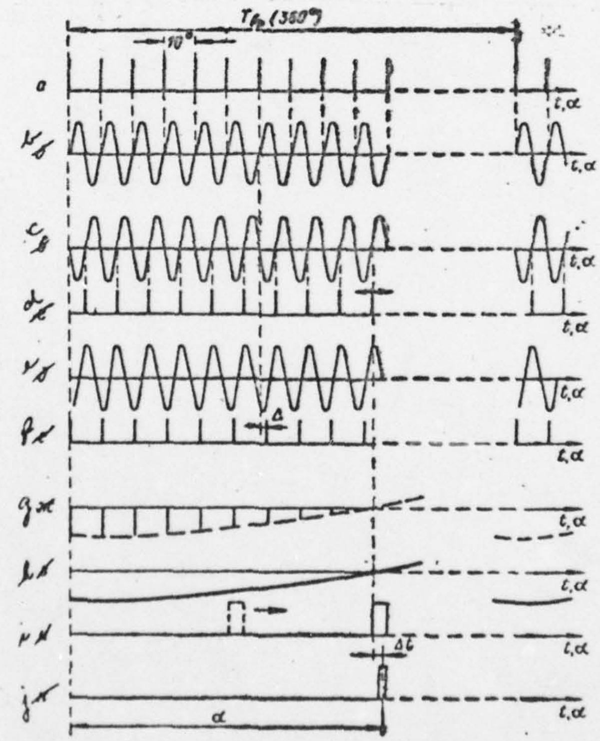
Hz. $$F_{35} = \frac{35}{T_{вр}} \approx 58{,}3\ [\text{гц} = \text{Hz}].$$

The sequence of reference pulses "36" approaches the time/temporary modulator of a precise channel BM_T. In modulator the momentum/impulse/pulses "36" are converted into the sine voltage of frequency 60 Hz (Fig. 2.16b), initial phase of which is determined by the temporary situation of momentum/impulse/pulses. Sine voltage reaches zero upon transition from negative values to positive at the onsets of momentum/impulse/pulses "36".

Page 79.

By this sine voltage are fed the phase inverters of precise and rough channels ΦB_{T} and ΦB_{r}.

Fig. 2.16. The time diagrams of the measuring unit of azimuth.



The rotors of phase inverters ΦB_r and ΦB_T are connected between themselves by reducer with transmission 1: 36 they have a communication/connection with the engine through the common/general/total reducer. During the rotation/revolution of engine to one complete revolution of the phase inverter of rough channel it corresponds "36" the complete revolutions of the phase inverter of a precise channel. During the rotation of rotor ΦB_T through 360° phase of output potential of phase inverter changes by 360°, which corresponds to voltage bias along time/temporary axis accurately on the voltage cycle of frequency 60 Hz, i.e., on the repetition period of reference pulses "36". The time interval between momentum/impulse/pulses "36" as it was explained earlier, corresponds to angle in space into 10°.

Page 80.

Therefore one complete revolution ΦB_T corresponds 10° change in the azimuth, and each degree of angle of rotation ΦB_T correspond 1/36° change in the azimuth. Thus, on angle of rotation ΦB_T can be determined with high accuracy the azimuth of aircraft. The axis, connected with the rotor of this phase inverter is a precise measuring axis.

The angle of rotation of the rotor of the phase inverter of rough channel the in "36" of times less than the angle of rotation of rotor ΦB_T, and therefore each degree of angle of rotation ΦB_r corresponds 1°

change in the azimuth, but one complete revolution of the phase inverter of rough channel is 360° charges in the azimuth. On angle of rotation ΦB_r it can be roughly, but unambiguously, is determined the azimuth of aircraft. The axis, connected with rotor ΦB_r, is rough measuring axis.

Out of phase the sine voltage of frequency 60 Hz from output/yield ΦB_T enters into time/temporary modulator BM_T and in it at the torque/moments of the achievement of zero of the sine voltage during its change from the negative to positive values they are developed momentum/impulse/pulses (Fig. 2.16c and d). The time interval between these momentum/impulse/pulses is equal to the interval between reference pulses "36", which corresponds to angular interval into 10°. During rotation ΦB_T the momentum/impulse/pulses are shift/sheared along time/temporary axis. With one complete revolution ΦB_T the momentum/impulse/pulses are shift/sheared along time/temporary axis accurately to the interval between momentum/impulse/pulses, or on 10° in angular unity. We will call these momentum/impulse/pulses movable desyatigradusnymi momentum/impulse/pulses.

Out of phase the sine voltage of frequency 60 Hz from phase inverter ΦB_r (Fig. 2.16e) will be feed/conducted to the time/temporary modulator of rough channel. There enters the sequence of reference pulses "35" (Fig. 2.16f). In modulator is realized modulation of these momentum/impulse/pulses with the aid of the sine voltage of frequency 60 Hz. The amplitude of each momentum/impulse/pulse of sequence "35" after modulation (Fig. 2.16g)

is proportional to the value of the sine voltage at the onset of this momentum/impulse/pulse. The temporary situation of reference pulses "35" A relative to zeros of sine voltage, i.e., relative to the sequence of momentum/impulse/pulses "36", changes periodically with difference frequency $F_{36} - F_{35}$, equal to the frequency of azimuth signals $F_A \approx 1.7$ Hz. Therefore go around of the modulated sequence of momentum/impulse/pulses has a frequency F_A (period is equal to the period of the rotation/revolution of azimuth antenna $T_{\beta p}$), and its initial phase is equal to the initial phase of the sine voltage, removed with ΦB_r.

Page 81.

The modulated sequence of momentum/impulse/pulses "35" is integrated, as a result of which is separate/liberated go around of this sequence (Fig. 2.16h). This voltage is utilized for the formation of gate pulses (Fig. 2.16i), which appear at the torque/moment of the achievement of zero going around during its change from the negative to positive values. During the rotation of the rotor of the phase inverter of rough channel changes the temporary situation of gate pulses, whereupon momentum/impulse/pulse on the period of rotation/revolution $T_{\beta p}$ or to 360° in angular unity.

Gate length is equal to 4.5° in angular sdinitsakh, i.e., is somewhat shorter than the half of the interval between desyatigradusnymi momentum/impulse/pulses. Gate pulse coincides with one of the movable desyatigradiusnykh momentum/impulse/pulses. During

the rotation/revolution of engine both these momentum/impulse/pulses simultaneously are moved along time/temporary axis, so that gate pulse coincides always with one and the same desyatigradusnym momentum/impulse/pulse. The temporary situation of these momentum/impulse/pulses unambiguously is determined by the angles of rotation of the rotors of the phase inverters of rough and precise channels.

Gate pulses and movable desyatigradusnye momentum/impulse/pulses are utilized for the measurement of azimuth. Let us examine work BIA during the azimuth determination, which is realized consecutively in two mode/conditions.

Search mode. This mode/conditions is utilized upon the start of instrumentation. To the time/temporary discriminator through the relay "search-tracking" are supplied the gate pulses from BM_{Γ} and azimuth momentum/impulse/pulses from receiver decay. To engine comes from grid/network the voltage of frequency 400 Hz and it rotates. During the rotation/revolution of engine the gate pulses are moved along time/temporary axis until they initiate to coincide with azimuth momentum/impulse/pulses (Fig. 2.16j). After the agreement of these momentum/impulse/pulses from time/temporary discriminator on relay the "poiskslezheniye" enters the voltage which moves relay. From engine is disconnected the line voltage, and it is stopped. Gate pulse ceases to be moved in time/temporary axis and now always coincides with azimuth momentum/impulse/pulse, as a result of which its temporary situation is determined by azimuth momentum/impulse/pulse, and it means the angle of rotation of rotor ΦB_{Γ} and of rough

measuring axis they correspond to the azimuth of aircraft with accuracy cf approximately 5°. Thus in search mode realized rough measurement cf azimuth.

Mode/conditions of tracking. In this mode/conditions is utilized the servo system, which switches on time/temporary discriminator, converter and engine.

Page 13.

From the angle cf rotation of rough axis is determined the integer of the complete revolutions of the phase inverter cf a precise channel, i.e., the integer of dozen degrees N - 1, that are placed in the measured azimuth α. The precise measuring axis determines accurately the position cf aircraft within the last/latter incomplete ten degrees. If during the measurement of azimuth the phase inverter of a precise channel turned itself to N - 1 complete revolutions and additionally to angle ϕ, then the measured azimuth of aircraft was equal to:

$$\alpha = \left(N-1+\frac{\varphi}{360^\circ}\right)10^\circ. \quad (2.18)$$

In accordance with expression (2.18) the instruments of PPDA take a reading of azimuth. Because cf use in the measuring unit cf the azimuth of the two-scale method of reading, the azimuth is measured unambiguously, also, with high accuracy.

§ 2.6. Principle of coordinate determination of aircraft on the earth/ground.

System PSBN makes it possible to determine on the earth/ground the polar coordinates of aircraft (slant range and azimuth) relative to the point of the arrangement/permutation of azimuth-ranging beacon. For this purpose on the earth/ground is utilized azimuth-ranging radio beacon and plan position indicator, but on aircraft is utilized the same instrumentation, as during ranging and azimuth on aircraft. Let us examine the principle of coordinate determination of aircraft on the earth/ground, by utilizing for this a block diagram (Fig. 2.17).

Fig. 2.17. Block diagram of coordinate determination of aircraft on the earth/ground in system RSBN-2.

Key: (1) the diagram of isolation pulse of demand. (2) encoder SZD.

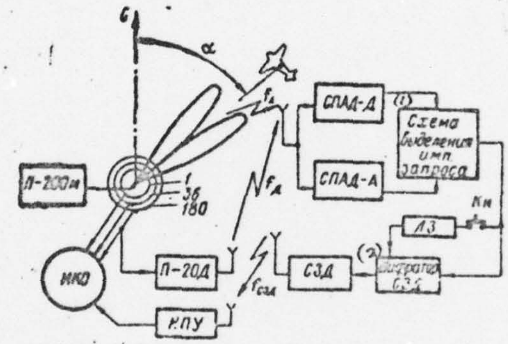
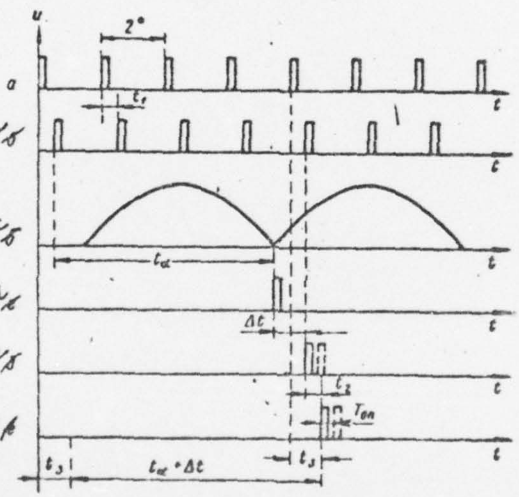


Fig. 2.17

Page 84.

For determining the coordinates of aircraft on the earth/ground is realized demand of aircraft equipment frcm the earth/ground and obtaining to it answer/response from aircraft. Inquiring signals are form/shaped with the transmitter of the relay of the range finder of P-20D. Tc this transmitter enter dvukhgradusnye momentum/impulse/pulses from ring, which is located on the axis of the rotation/revolution of azimuth antenna, on which established/installed 180 contacts. Dvukhgradusnye momentum/impulse/pulses (Fig. 2.18a) in transmitter the P-20D are coded (each momentum/impulse/pulse is converted intc three-pulse interval-time/temporary code) and at the carrier frequency of ranging channel $f_Д$ they transmit to aircraft. These inquiring signals, transmitted from the transmitter of P-20D to aircraft, are called signal the "demand of indication". On aircraft the signals the "demand of indication" are received as the ranging channel cf receiver decay and after amplification and detection approach the decoder of inquiring signals (see Fig. 2.14). Here signals are decoded, as a result of which at output/yield decoder of inquiring signals are separate/liberated dvukhgradusnye momentum/impulse/pulses (Fig. 2.18b) which delay with respect to the same dvukhgradusnym momentum/impulse/pulses on the earth/ground on value t_1 = 4/c, where r delay the distance between the beacon and the aircraft.

Fig. 2.18. The time diagrams of system RSBN-2 during coordinate determination of aircraft on PEI.



Page 85.

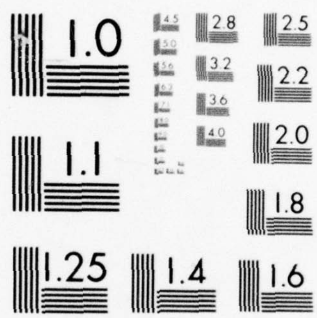
The transmitter of azimuth signals P-200M works just as during the measurement of azimuth on aircraft, i.e., it sends to aircraft with the aid of azimuth antenna azimuth signals (Fig. 2.18c). These signals are received as the azimuth channel of receiver decay, they enter then into the shaping unit of azimuth momentum/impulse/pulses, at output/yield of which is separate/liberated azimuth momentum/impulse/pulse (Fig. 2.18d). As it was shown, time of the appearance of azimuth momentum/impulse/pulses on aircraft t_A is determined by the azimuth of aircraft (see equation 2.12).

Dvukhgradusnye and azimuth momentum/impulse/pulses approach the diagram of the isolation of interrogation pulses, which enters the receiver decay. This diagram of all dvukhgradusnykh momentum/impulse/pulses in each turn of azimuth antenna separate/liberates the only one dvukhgradusnyy momentum/impulse/pulse (Fig. 2.18e), that that the first comes after the beginning of azimuth momentum/impulse/pulse. This chosen dvukhgradusnyy momentum/impulse/pulse is directed to for encoder the SZD in which it is converted into three-pulse interval-time/temporary code. Under the effect of this code the transmitter SZD generates the high-frequency coded signal at frequency $f_{C3Д}$ and with the aid of the transmitting antenna emits it into space. The signal, which goes from aircraft to azimuth-ranging beacon, is called signal the "answer/response of indication". On the earth/ground the signal the "answer/response of

AD-A050 082 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO F/G 17/7
RADIO EQUIPMENT FOR AIR NAVIGATION,(U)
MAY 76 G P ASTAFYEV, V V GRACHEV, A S KULCHIY

UNCLASSIFIED FTD-ID(RS)T-0659-76 NL

3 OF 4
AD A050082



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

indication" is received as the receiver of NFU, it is amplified in it and is decoded. At the output/yield of receiver is separate/liberated reciprocal momentum/impulse/pulse (Fig. 2.18f) which delays with respect to the chosen on aircraft dvukhgradtsnomu momentum/impulse/pulse for a period $t_2 = r/c$.

Reciprocal momentum/impulse/pulse is supplied to the control electrode of cathode-ray tube PPI and creates on scope the mark of aircraft.

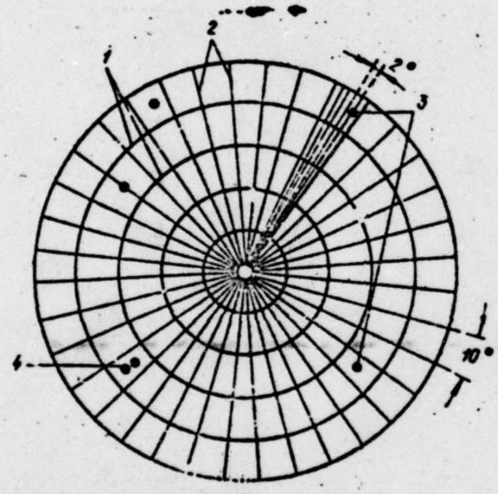
Reciprocal momentum/impulse/pulse (see Fig. 2.18) it contains the information about the azimuth of aircraft and distance of it. The information about slant range from beacon to aircraft is contained in the time lag of reciprocal momentum/impulse/pulse with respect to its caused dvukhgradusnomu momentum/impulse/pulse, since time lag $t_3 = t_1 + t_2 = 2r/c$ is directly proportional to the slant range r. The information about the azimuth of aircraft with tochnonost'yu to 2° is contained in the time lag of reciprocal momentum/impulse/pulse with respect to the torque/moment of passage by the azimuth antenna of northern direction, since reciprocal momentum/impulse/pulse can be formed in time interval, which corresponds 2°, after the appearance of an azimuth momentum/impulse/pulse.

Page 86.

In azimuth-ranging beacon is applied the plan position indicator, a similar PPI of radar stations. Sweep circuit PPI is started by the dvukhgradusnymi momentum/impulse/pulses, removed from the slip ring.

connected with ring with 180 contacts. Therefore on screen PPI is created the raster of scanning/sweep during the rotation/revolution of the azimuth antenna, which consists of 180 sweep traces (Fig. 2.19).

Fig. 2.19. PPI scope.



The mark of aircraft will be illuminated on that sweep trace which is created by the dvukhgradusnym momentum/impulse/pulse, which caused reciprocal momentum/impulse/pulse. The position of the mark of aircraft on sweep trace is determined by a delay in the reciprocal momentum/impulse/pulse with respect to the dvukhgradusnomu momentum/impulse/pulse, which launched this sweep trace. Therefore distance on screen from center to the mark of aircraft is proportional to inclined distance from beacon to aircraft in space.

Thus, the position of target blip on scope is determined by the actual position of aircraft in space relative to beacon and on target blip they can be measured the coordinate of aircraft (slant range and azimuth).

For the reading of the coordinates of aircraft on screen is created electronic scale grid, for which to cathode-ray tube they are supplied scale range marks and azimuth markers.

Page 87.

As azimuth markers are utilized the desyatigradusnye momentum/impulse/pulses, removed from ring "36". These momentum/impulse/pulses brighten sweep trace, multiple 10°. The illuminated sweep traces are utilized as azimuth scale grid. To indicator, besides desyatigradusnykh momentum/impulse/pulses, are supplied also the momentum/impulse/pulses from the ring on which is established/installed the only one contact, which corresponds to

northern antenna bearing. These momentum/impulse/pulses provide illumination on the scope of the line of zero azimuth.

Special feature/peculiarity the PPI of the azimuth-ranging beacon of system RSBN in comparison with the indicators of radar stations is the fact that the mark of aircraft is moved by shocks from one sweep trace to adjacent during a smooth change in the azimuth of aircraft. This is explained by the fact that for the formation of reciprocal momentum/impulse/pulse is utilized one of the dvukhgradusnykh momentum/impulse/pulses. In this case the maximum error in determination of azimuth is 2°. For displacement paths of the azimuth scale to 1° they attain that the error becomes symmetrical relative to zero and decreases two times (+-1°).

During coordinate determination of aircraft on the earth/ground is utilized the same ranging channel (transmitters of P-20D and SZD) that and during ranging on aircraft. In order that the signals the "demand of indication" and the "answer/response of indication" would not affect the work of ranging channel during ranging the aircraft, they are coded by three-pulse code, while inquiring and response signals take the form of two-pulse code. On screen PPI are formed the marks of all aircraft, which are located in the zone of action of azimuth-ranging beacon and which have the connected on the frequency-code channel of this beacon equipment for system RSBN. Thus, the system provides mapping onto the PPI of the information about air situation.

Additionally system makes it possible for dispatcher to identify aircraft, i.e., from all aircraft, mapped onto PPI, separate/liberates

one at the given instant of dispatcher the aircraft interesting. For this the dispatcher must on communications radio station ask the crew of its aircraft interesting to include/connect identification. Identification is included by pushing of knob the saturation coefficient (see Fig. 2.17). The chosen dvukhgradusnyy momentum/impulse/pulse approaches encoder SZD in two ways - directly from the output/yield of the diagram of the isolation of interrogation pulses and through the delay line.

~~MT/ST-76-659~~

~~jm91~~

SUBJECT CODE D214

Page 88.

Therefore to SZD will manufacture instead of one signal the "answer/response of indication" two such signals, shifted in time relative to each other for a period T_{on} that provided with delay line. On the earth/ground at the output/yield of the receiver of NPU will be isolated two reciprocal momentum/impulse/pulses, shifted for a period T_{on}.

Those momentum/impulse/pulses will create on screen the illumination of aircraft in the form of two luminescent spots (see Fig. 2.19), several those which were displaced relative to each other

on sweep trace. Cn the doubled mark cf aircraft the dispatcher produces its identification. After this the dispatcher can request and identify the following aircraft.

Cn aircraft for correct position finding cf aircraft there is a need for the identification of ground-based azimuth-ranging radio beaccn. For this from beacon tc aircraft transmit the call signals. The transmission of call is conducted thus. Signals the "demand of indication" are manipulated on telegraph alphabet. During pause the code cf signals the "demand of indication" is distorted - instead of the three-pulse ccde transmits two-pulse. This code does not pass through the decoder of the inquiring signals of receiver decay and during pause there signal is absent. Telegraph signal after the decoder inquiring signalcvpodaetsya into crew intercommunication equipment and is heard out in the form of the determined for this beaccn set cf pcints and dash. The transmission of call is conducted pericdically. Entire cycle of transmissicn duration 30 s. From them 15 s transmit the call, and into others 15 s goes normal operation regarding the coordinates of aircraft cn the earth/ground.

§ 2.7. Cperating modes of aircraft equipment.

Aircraft equipment can be utilized in two basic operating modes - navigaticral and landing.

Navigaticnal operating mode is applied in flight of aircraft enroute in the zcre of action of azimuth-ranging beacons RSBN [РСБН] - Short-range Navigation Radio System] and in the prelanding

maneuvering. Control of work of aircraft equipment in this mode/conditions is realized with the aid of the control panel of navigator and assembly of control SRP. In navigational mode/conditions continuously and automatically is measured slant range and the azimuth of aircraft otnositel'no the RNT which are utilized for the driving of aircraft along the predetermined trajectories, for which instrumentation it has a series of special operating modes.

Let us examine work of aircraft equipment in these mode/conditions.

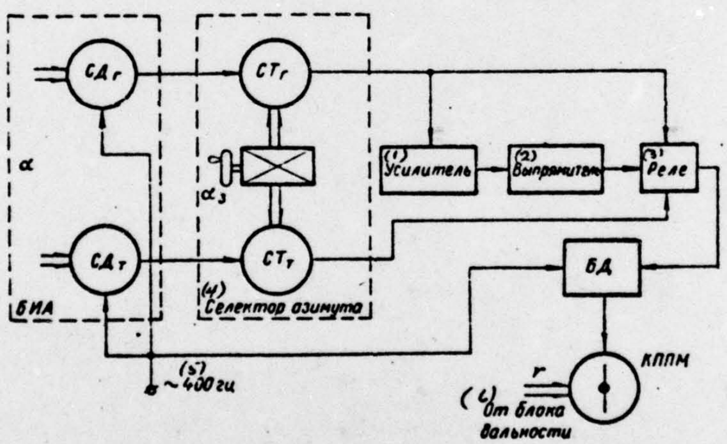
Page 89.

Mode/conditions of the driving of aircraft along the assigned azimuth.

This mode/conditions is included by the function selector on the control panel of navigator (position !tsazimut to" and "azimuth from") and is realized with the aid of the selector of the azimuth, arrange/located there. Work of instrumentation in this mode/conditions occurs as follows (Fig. 2.20).

Fig. 2.20. Block diagram of the driving of aircraft along the assigned azimuth.

Key: (1) amplifier. (2) rectifier. (3) relays. (4) the selector of azimuth. (5) Hz. (6) from the assembly of val'nosti.



In the selector of azimuth are established/installed the synchro-transformers CT_{Γ} and CT_{T} rotors of which are connected between themselves by reducer they can be turned to any angle, which corresponds to the assigned azimuth $\alpha_{З}$. The stator windings of these selsyns are connected with the stator windings of the sel'sinovdatchikov of rough and precise channels $CД_{\Gamma}$ and $CД_{T}$ being located into BIA. The rotors of selsyn transmitters $CД_{\Gamma}$ and $CД_{T}$ are connected with rough and precise measuring axes, and therefore the angle of rotation of rotors corresponds to the actual azimuth of aircraft α. The rotor windings of selsyn transmitters are fed by the voltage of frequency 400 Hz. From the rotor windings of synchro-transformers is remove/taken the voltage of frequency 400 Hz whose amplitude is proportional to the sine of displacement angle $\Delta\alpha = \alpha - \alpha_3$ between the rotors of selsyn transmitters and synchro-transformers:

$$U_{вых} = U_m \sin(\alpha - \alpha_3) = U_m \sin \Delta\alpha,$$

a phase (0 or 180°) it depends on the sign of disagreement/mismatch.

Page 90.

The diagram, which ensures the driving of aircraft along the assigned azimuth, consists of two channels: gurbogo and precise, work

khotorykh odninakova. During large disagreement/mismatches works rough channel ($\Delta\alpha > 9 - 12°$). The voltage, removed from rotor winding CT_r is amplified, is straighten/rectified and affects the relay whose contacts are located in this position by which to balance detector BD enters the voltage from the rotor winding of the synchro-transformer of rough channel. Furthermore, on BD is supplied as supporting/reference the same voltage, by which are fed the rotors of selsyn transmitters. Balance detector reacts to amplitude and phase of the entering to it voltage and develops direct/constant voltage whose value is proportional to the amplitude of stress from rotor CT_r a polarity it is determined by the phase of this stress. Thus at output/yield BD is formed direct/constant voltage, proportional to the sine of displacement angle,

(2.19) $U=k\sin\Delta\alpha$

positive or negative polarity depending on the sign of disagreement/mismatch. This stress is supplied to the vertical arrow/pointers of the instruments of KPP [КПП] - flight director] and causes their deflection.

During a decrease in the disagreement/mismatch $\Delta\alpha$ the amplitude of the stress, removed from rotor winding CT_r, decreases and becomes insufficient for the function of relay. Its contacts are moved at another position and on BD it begins to enter stress with rotor winding CT_T. Work of a precise channel is analogous to work of rough

channel and at output/yield BD it is separate/liberated as before direct/constant voltage, determined by value $\Delta\alpha$. Pilot's problem with the driving of aircraft in the assigned azimuth is this aircraft control with which the vertical rifleman/gunners of KPP'S instruments would be situated in center. In this case stress U, removed with BD, will be equal to zero, and that means, as this follows from equation (2.19), $\Delta\alpha = \alpha - \alpha_3 = 0$, hence $\alpha = \alpha_3$, i.e., the actual azimuth of aircraft is equal to the assigned azimuth. Thus, aircraft will move over the line of the assigned azimuth, if the vertical rifleman/gunners of KPP are held in the center of instruments.

During small disagreement/mismatches between the actual and that which was assigned azimuths the stress level U and the throw of the pointer of KPP δ_{CTP} directly proportional to the angular deflection of aircraft from the assigned azimuth:

$$\delta_{\text{стр}_1} = k_\alpha \cdot \Delta\alpha, \tag{2.20}$$

where k_α is the coefficient, which determines the angular instrument sensitivity of KPP.

Page 91.

In order to ensure the identical accuracy of the stabilization of aircraft on the line of the assigned azimuth independent of omnidistance r, is desirable to ensure throw of pointer, proportional

to linear lateral deflection Δl aircraft from Assigned Track Line, i.e.

(2.21) $\delta_{\text{стр}} = k_l \Delta l,$

where k_l is the constant coefficient, which determines the linear instrument sensitivity of KPP.

Linear lateral deflection is connected with the angular during small deflections following equation:

(2.22). $\Delta l = r \cdot \Delta \alpha.$

After substituting (2.22) in (2.21), we will obtain

(2.23). $\delta_{\text{стр}} = k l r \cdot \Delta \alpha.$

From the comparison of expressions (2.20) and (2.23) it is evident that for providing throw of pointer it is proportional to linear lateral deflection, the angular instrument sensitivity of KPP must change during a change in the omnidistance according to the law

(2.24). $k_\alpha = k_l r.$

The indicated change in the angular instrument sensitivity of KPP is achieved because of the communication/connection of these instruments with the measuring axis of the range of the measuring unit of range.

Output potential of balance detector reaches zero not only with $\Delta\alpha = 0$, but also with a difference of the actual azimuth from that which was assigned at an angle of 180°. However, with this value of actual azimuth the stabilization of aircraft on Assigned Track Line is impossible, since the side of deflection the rifleman/gunner of KPP will not correspond to the side of the deflection of aircraft from the line of the assigned azimuth.

Mode/conditions of the driving of aircraft on the designated orbit.

This mode/conditions is included in the presence of the position of the function selector "orbit left" or "orbit right" and is realized with the aid of the selector of orbit, arrange/located on the control panel of navigator. Work of instrumentation in the mode/conditions of the driving of aircraft on the designated orbit occurs in accordance with the diagram, depicted on Fig. 2.21.

In selector the orbits are established/installed the receiving synchro and the doubled potentiometer, corrected with reducer. The Ubly of the rotation of the rotor of receiving synchro and potentiometer are determined by the assigned radius of orbit r_3. Potentiometer is connected with the rough measuring axis of the

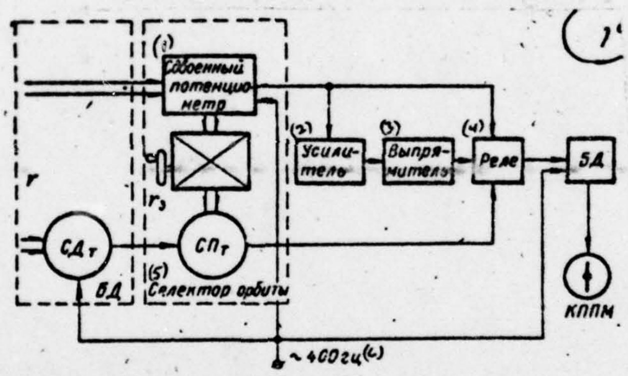
measuring unit of range.

Page 92.

The stator windings of receiving synchro are connected with the stator windings of the selsyn transmitter of a precise channel СД$_Т$, arrange/located in the measuring unit of range. The rotor of this selsyn connect with a precise measuring axis. The angles of rotation of measuring axes are determined by the actual distance r from aircraft to beacon. From potentiometer and from the rotor winding of the receiving synchro of a precise channel СП$_Т$ is remove/taken the alternating voltage of frequency 400 Hz whose amplitude depends on the error angle of potentiometers or rotors of selsyns, and the phase of this voltage (0 or 180°) is determined by the side of disagreement/mismatch. Since the angles of rotation of potentiometers and rotors of selsyns are determined by the actual and assigned distance, the amplitude of the removed stresses depends on value $\Delta r = r - r_з$, and the phase is determined by the sign of this value.

Fig. 2.21. Block diagram cf driving aircraft on the designated crbit.

Key: (1) the doubled potenticmeter. (2) amplifier. (3) rectifier. (4) relays. (5) the selector cf orbit. (6) ~400 Hz.



Just as the diagram of the driving of aircraft along the assigned azimuth, the diagram of driving on the designated orbit consists of two channels - rough and precise. During large disagreement/mismatch ($\Delta r > 9 - 13$ km) works rough channel. To balance detector enters the stress from the potentiometer through the relay which is controlled by the intensive and unidirectional voltage of rough channel. After the disagreement/mismatch decreases to value 9-13 km, the voltage, removed from potetsiometrov, will be insufficient for function relay and its contacts they will move at another position. On balance detector will initiate to enter the voltage from rotor winding $C\Pi_T$ and it will work a precise channel.

Page 93.

At the output/yield of balance detector is developed direct/constant voltage whose value during small disagreement/mismatches is proportional to value Δr:

(2.25). $U = k \cdot \Delta r.$

The polarity of this voltage depends on the phase of the voltage, which enters on the inlet of balance detector, i.e., it is determined by the sign of disagreement/mismatch. Voltage U approaches the vertical arrow/pointers of the instruments of KPP which are deflected,

showing value and the side of the deflection of aircraft from the assigned radius

(2.26). $\delta_{стр} = k_1 \cdot \Delta r.$

With the driving of aircraft on the designated orbit the vertical arrow/pointers of KPP'S instruments must be located in the center of the scale. In this case $\delta_{стр}$ must be equal to 0 and as it follows from equation (2.26),

(2.27) $\Delta r = r - r_3 = 0,$

whence $r = r_3$, i.e., the actual distance of aircraft of beacon is equal the assigned to distance. Thus, aircraft will move over the trajectory, any point of which ravnoudalena from beacon to value r_3. This trajectory is the circle with radius of r_3 whose center coincides with the point of setting azimuth-ranging beacon.

In this operating mode in KPP'S instruments enters the voltage, which depends on linear lateral deflection Δr on the designated orbit, and therefore instruments they do not need sensitivity control.

Mode/conditions of the driving of aircraft on any rectilinear route.

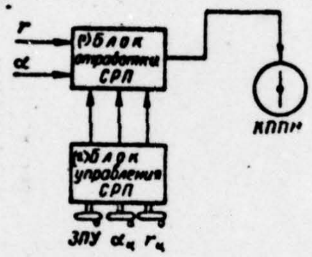
This mode/conditions is realized with the aid of computer SRP and is

included in the presence of the position of the function selector "SRP". Work of instrumentation in the mode/conditions of driving on any rectilinear route can be explained with the aid of block diagram (Fig. 2.22).

With the aid of the assembly of control SRP are establish/installed the parameters of specified track Assigned Track Line.

Fig. 2.22. Block diagram of the driving of aircraft on any rectilinear route.

Key: (1) the assembly of final adjustment SRP. (2) the assembly of control SRP.

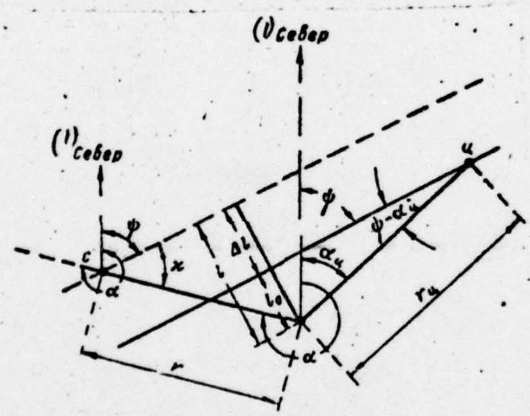


Page 94.

Such parameters are the given course angle ψ and polar coordinates relative to the RNT of any point, arrange/located on Assigned Track Line. This point conditionally is called target/purpose (point q in Fig. 2.23), and its polar coordinates - by the azimuth of target/purpose $\alpha_{\text{ц}}$ and by the distance of target/purpose $r_{\text{ц}}$. The given course angle determines direction Assigned Track Line in space, and the assignment of the coordinates of one point Assigned Track Line record/fixes the necessary line. Thus, the parameters ψ, $\alpha_{\text{ц}}$ and $r_{\text{ц}}$, the established/installed on assembly controls SSP, are uniquely determined in space Assigned Track Line. These parameters in the form of electrical signals approach the assembly of final adjustment SRP. There from the measuring unit of azimuth and measuring unit of range enter actual azimuth α and the actual range r.

Fig. 2.23. To the explanaticn cf work of the diagram of the driving of aircraft cn any rectilinear route.

Key: (1) north.



The assembly of final adjustment SFF realizes transformation of polar coordinates into rectangular ortodromicheskis. Work of this assembly let us explain with the aid of Fig. 2.23. The assembly of final adjustment, utilizing the entering it signals, calculates the shortest distance from beacon to Assigned Track Line l_0, which (see Fig. 2.23), it is determined by the equation

(2.28). $l_0=r_n \sin(\psi-\alpha_n)$..

Then the assembly of final adjustment calculates angle γ between direction in beacon from the actual position of aircraft S and the line of parallel Assigned Track Line and that passing through the point of the actual position of aircraft. By examining angles around point S, it is possible to see, that

(2.29). $\psi+\gamma+\pi=\alpha$, i.e. $\gamma=\alpha-\psi-\pi$.

Page 95.

After determining angle γ, the assembly of final adjustment calculates shortest distance from beacon to the line, parallel to Assigned Track Line and passing through the point of the actual position of aircraft,

(2.30). $l=r\sin\gamma=r\sin(\alpha-\phi-\pi)$.

After this determined shortest distances l_0 and l are converted into the voltages, proportional to them:

and (2.31) $U_0=kl_0$ и $U=kl$. [и = and]

where k is a proportionality factor.

Then voltages U_0 and U are compared, as a result of which is developed their difference $\Delta U = U - U_0$.

Voltage ΔU, as this follows from expressions (2.31), is directly proportional to a difference in shortest distances l_0 and in l:

(2.32). $\Delta U=k(l-l_0)=k\cdot\Delta l$.

This means that it is proportional to the linear lateral deflection of aircraft Δl from specified track.

Thus, in mode/conditions "SRP" computer develops direct/constant voltage, directly proportional to the linear lateral deflection of aircraft from Assigned Track Line. This voltage is supplied to the vertical arrow/pointers of the instruments of KPP and causes their deviation of value

(2.33). $\delta_{\text{стр}} = k_l \cdot \Delta l.$

Pilot's problem with the driving of aircraft in any rectilinear route is this control of it, during which the vertical rifleman/gunners of KPP'S instruments would be situated in the center of ekaly. In this case $\delta_{\text{стр}} = 0$ and as it follows from equation (2.33), Δl = 0, i.e., the aircraft moves over specified track.

The accuracy of the driving of aircraft in the predetermined trajectory in the mode/conditions of "SPP" is worse than into rezhimaz "azimuth" and "orbit", since in this mode/conditions is conducted transformation of coordinates by computer and to the errors of system RSBN-2 is added the error of computation. As a whole this accuracy kharkaterizuyetsya by error 2.5 km. The accuracy of the driving of aircraft in the predetermined trajectories in mode/conditions "azimuth" and the "orbit" is characterized by errors 0.3° and 300 m respectively.

Signaling of the flight/span of the aircraft of the given point of space.

In aircraft equipment of RSBN-2 is provided the signaling of the torque/moment of the approach of aircraft to the given point of space and torque/moment of its flight/span. For this in instrumentation are utilized two comparison circuits, connected with warning lamps

"approach to zone" and the "flight/span of zone".

Page 96.

To comparison circuits are supplied the actual values of range and azimuth from the range unit and measuring unit of azimuth and the rated values of range and azimuth from the selectors of range and orbit. In comparison circuits is conducted the comparison of the actual and rated values of range and azimuth and the formation/education of differences in these values: $\Delta r = r - r_3$ and $\Delta \alpha = \alpha - \alpha_3$.

Further the diagram of signaling works as follows. When the absolute value of the indicated differences in each comparison circuit simultaneously becomes the less determined values, it occurs the srabatyvanei of the diagram of signaling, which ignites the appropriate tube. The threshold values at which wear/operates the signaling, are selected different for two comparison circuits and therefore one of them it provides the signaling of approach to the given point, but another - the signaling of the flight/span of this point.

The diagram of the signaling of approach provides the ignition of warning lamp "approach to zone" during satisfaction of the following condition:

$$\Delta r = 8\text{—}20 \text{ км};$$
$$\Delta \alpha = 2\text{—}10^\circ.$$

The diagram of the signaling of the flight/span of the given point causes the firing of warning lamp the "flight/span of zone" with

$$\Delta r = 300-900\ м;$$
$$\Delta \alpha = 0{,}3-0{,}9°.$$

Thus, aircraft equipment of system provides the signaling of approach and flight/span of this point of space (point 5 in Fig. 2.1), polar coordinates of which are assigned on the selectors of azimuth and orbit.

Mode/conditions of cloud penetration along the predetermined trajectory.

This mode/conditions is included by toggle switch on the control panel of navigator and is realized as follows (Fig. 2.24).

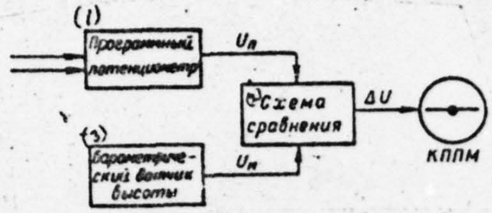


Fig. 2.24. Block diagram of cloud penetration on predetermined trajectories.

Key: (1) the programmed potentiometer. (2) comparison circuit. (3) barometric altitude sensor.

Page 97.

In range unit is established/installed the programmed potentiometer, connected with the measuring axis of range. The angle of rotation of the wiper for this reason will be proportional to distance from aircraft to the azimuth-ranging beacon of system. From potentiometer is remove/taken direct/constant voltage, which is certain function of the distance:

(2.34). $U_{n}=f(r).$

The character of this function is determined by the form of the programmed potentiometer and changes depending on aircraft type, but always the function during a decrease in the distance is decreasing. Therefore during the approach of aircraft to beacon the voltage, removed from the programmed potentiometer, decreases. For the assignment of line of descent, besides the programmed potentiometer, is utilized also barometric altitude sensor. From this sensor is remove/taken direct/constant voltage, directly proportional to height/altitude H (barometric) of flight !

(2.35) $U_{H}=kH,$

where k is a proportionality factor.

Voltages from the programmed potentiometer and barometric sensor will be feed/conducted to comparison circuit where is formed their difference:

(2.36). $\Delta U = U_{п} - U_{H}.$

The signal of direct current ΔU is supplied to the horizontal arrow/pointers of the instruments of KPP and causes their deviation. By pilot's problem in this mode/conditions is this aircraft control by changing in order that the horizontal rifleman/gunners of instruments would be situated in the center of the scale. In this case a voltage difference ΔU = 0 and, therefore,

(2.37). $U_{п} = U_{H}.$

After substituting into the last/latter equation of the value of the voltages $U_{п}$ and U_{H} from (2.34) and (2.35), let us find

(2.38). $H = \frac{f(r)}{k}.$

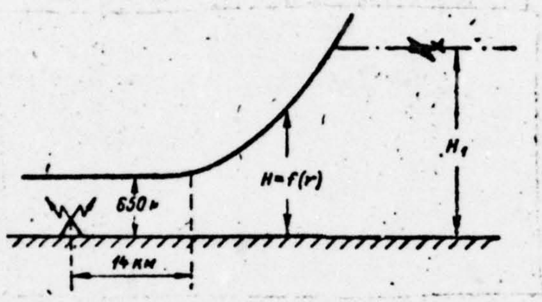
Equation (2.38) shows that when using a mode/conditions of cloud penetration the flight altitude aircraft during its

approach/approximation toward beacon decreases according to the law, assigned by the programmed potentiometer (Fig. 2.25). Aircraft, flying at the constant height/altitude H_1, reaches the predetermined trajectory of cloud penetration (rifleman/gunner of instrument it approaches the center of the scale).

Page 98.

When using this mode/conditions the aircraft during further approach/approximation to beacon will lower according to the law, assigned by the programmed potentiometer. Decrease is conducted to height/altitude 650 m at a distance 14 km of beacon, whereupon aircraft converts itself into level flight *. [[FOOTNOTE * the examined operating mode on the aircraft of the civil aviation is not applied. ENDFOOTNOTE]].

Fig. 2.25. Character of line of descert in the mode/conditions of cloud penetration.



The landing operating mode of aircraft equipment is included by toggle switch on the control panel of pilot either by the switch of operating modes on the control panel of pilot or by the switch of operating modes on the control panel of navigator. Aircraft transmitter SZD and receiver decay are tuned to one of the frequency-code channels of the landing instrumentation of system, and aircraft receiver picks up signal of course and glide beacons KRM-4 and of GRM-4, and also the response signals of the landing relay of range finder. The indicated signals are utilized for an indication on the instruments of the KPPM of the position of aircraft relative to the line of gliding/planning in horizontal and vertical planes and on the instruments of the PPDA of distance of the glide-path beacon on which is placed the landing relay of range finder. The signals of azimuth-ranging beacon in this operating mode as aircraft equipment are not received and therefore the data on azimuth and range the aircraft of relatively this beacon by instruments they are not represented.

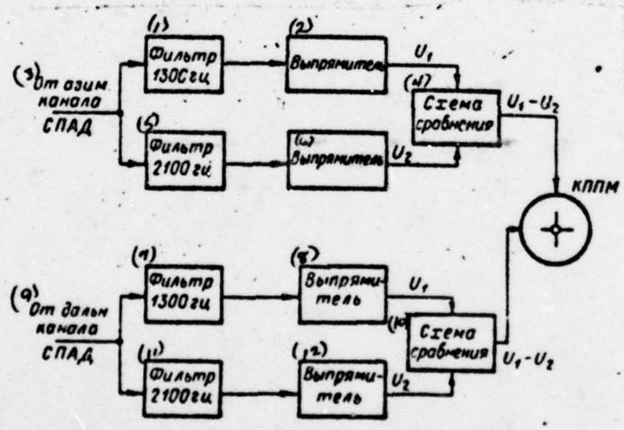
For the assignment of the line of gliding/planning on the earth/ground are establish/installed the localizer beacon KRM-4 and glide-path beacon GRM-4. The basic information about these beacons and their operating principle was examined earlier (see Chapter of 4 sections 1). The signals of these beacons are accepted on you smaclete by receiver decay, they are amplified by it, are detected and after this are supplied to unit landings (see Fig. 2.14).

Page 99.

This unit processes the signals of course and glide beacons, i.e., separate/liberates the containing in them navigational information about aircraft attitude relative to the line of gliding/planning the unit of landing it consists of two channels (Figs. 2.26), one of which is intended for processing the signals of localizer beacon, and by another is intended glide-path beacon. Let us examine of one of these channels.

Fig. 2.26. Structure of the unit of landing.

Key: (1) filter 1300 Hz. (2) rectifier. (3) from azim channel decay. (4) filter 2100 Hz. (6) rectifier. (7) filter 1300 Hz. (8) rectifier. (9) from the dal'n of channel decay. (10) comparison circuit. (11) filter 2100 Hz. (12) rectifier.



Signal amplitude envelope of localizer beacon, the representing sequence of the square pulses of frequencies 1300 and 2100 Hz, from output/yield UPCh of the azimuth channel of receiver decay is supplied simultaneously to two filters, tuned to frequencies 1300 and 2100 Hz. The filter, tuned to a frequency 1300 Hz, separate/liberates the fundamental harmcric of the sequence of the momentum/impulse/pulses of this frequency. The amplitude of sinuscidal output potential of this filter directly proportional the signal level, emitted on one of the radiation patterns of localizer beacon. At the output/yield of the filter, tuned to a frequency 2100 Hz, is separate/liberated the sine voltage whose amplitude directly proportional the signal level, emitted according to the second radiation pattern of beacon.

Both sine voltages are straighten/rectified, as a result of which after rectifiers are formed direct/constant voltages U_1 and U_2, which directly proportional to the values of the signals, transmitted by two radiation patterns of localizer beacon.

Page 100.

Direct/constant voltages U_1 and U_2 enter comparison circuit where they are deducted. A voltage difference $U_1 - U_2$ is supplied to the vertical arrow/pointer of the instrument of KPPM. As it follows from the operating principle of the localizer beacon of KRM-4, the voltage difference $U_1 - U_2$ is determined by the value of the angular deflection of aircraft from the plane of landing pattern, and signal

polarity $U_1 - U_2$ depends on the side of deflection. For this reason the vertical arrow/pointer of instruments KIIM will show value and side of the deflection of aircraft from the line of gliding/planning in horizontal plane.

The second channel of the unit of landing works analogously, with by that only difference, that to it are supplied the signals of the glide-path beacon of GRM-4 from output/yield UPCh of the ranging channel of receiver decay. The formed voltage difference $U_1 - U_2$ in this channel, which is determined by value and the side of the deflection of aircraft from glide path in vertical plane, is supplied to the horizontal arrow/pointer of instruments KPPM. In connection with this the horizontal rifleman/gunners will show the value of angular deflection and the side of the deflection of aircraft from the line of gliding/planning in vertical plane.

The information about distance of touchdown point (it is more precise to the point of the arrangement/permutation of glide-path beacon) is separate/liberated on aircraft in landing attitude as a result of work of pulse ranging system with the relay retort of signals. Inquiring signals are formed by aircraft equipment, and reciprocal - by the landing relay of range finder, establish/installed in glide-path beacon. The principle of ranging on aircraft in landing attitude is analogous to the principle of ranging in navigational mode/conditions (see Fig. 2.4) with that difference, that instead of the relay of the range finder of azimuth-ranging radio beacon is utilized the landing relay of range finder. Structure of this relay of range finder the same as navigational relay. Difference only in

the characteristics of the landing relay cf the range finder which provides the lesser range (50 km at height/altitude 1000 m); therefore the power of response signals is also less than in azimuth-ranging beacon. The landing relay of range finder possesses lesser capacity (30 aircraft). The accuracy of ranging landing attitude is somewhat lower than in navigational mode/conditions - it is ±250 m.

MT/ST-76-0659

[redacted]

[redacted]

Pages 101-132.

§ 2.8. Development of azimuth-ranging system.

Azimuth-ranging system RSBN-2 after having emerged to operation continued to be improved on by the sleduyushchimosnovnym direction:

- an improvement in the characteristics and an increase in the reliability of work of ground-based radio beacons;

- the development of the simplified ground beacons for the instrumentation of the local aerial lines;

- the translation/conversion of aircraft equipment into semiconductor devices;

- an increase in the reliability of work of aircraft equipment;

- the expansion of the functions of the aircraft equipment by aggregation with other on-board systems;

- the development of the simplified aircraft equipment for the aircraft of the local aerial lines.

The further development of the azimuth-ranging beacon of system RSBN-2 is the beacon of the type of RSBN-4N. In this beacon is

provided 100o/o redundancy of the most important equipment, is provided for the possibility of work to extension plan position indicators and are improved the fundamental characteristics. The simplified block diagram of the beacon of RSBN-4N (without spare equipment) is given in Fig. 2.27.

The operating principle of this beacon is accurate the same as the azimuth-ranging beacon of RSBN-2N. For measurement on the aircraft of omnidistance the aircraft equipment emits inquiring signals. These signals are received as the receiver of beacon and after amplification enter decoder. Decoded with decoder signal is supplied to the encoder of the ranging channel where is realized the coding of response signal. Reciprocal code enters the transmitter of ranging channel, which consists of modulator, driver, the frequency multiplier and pulse high-frequency oscillator. Developed by this transmitter high-frequency response signal is emitted with the aid of the omnidirectional in horizontal plane antenna. This same transmitter is utilized for the emission/radiation of signals the "demard of indication". The coding of these signals is realized by an encoder of ranging channel during the supplying to it from the drive of the rotation/revolution of the natenny of dvukhgradusnykh momentum/impulse/pulses.

For measurement on the aircraft of azimuth the beacon transmits azimuth and reference signals. These signals are generated by the azimuth transmitter which consists of driver, two frequency multipliers, two high-frequency oscillators - pulse and continuous and the modulator, connected with pulse generator.

Page 102.

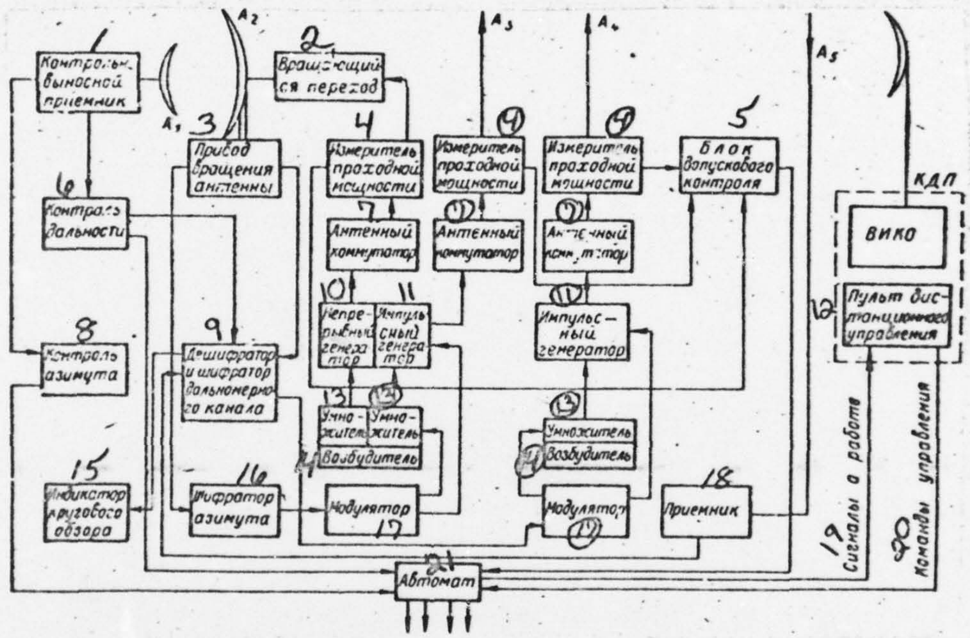


FIG. 2.27.

Fig. 2.27. Block diagram of the radio beacon of RSBN-4N.

Key: (1) control extension receiver; (2) the revolving change; (3) the rotator; (4) the meter of passage power; (5) the unit of dopuskovogo control; (6) the control of range; (7) antenna commutator; (8) the control of azimuth; (9) the decoder and the encoder of ranging channel; (10) continuous oscillator; (11) pulse generator; (12) the panel for remote control; (13) multiplier; (14) driver; (15) plan position indicator; (16) the encoder of azimuth; (17) modulator; (18) receiver; (19) signals a to work; (20) steering commands; (21) automatic machine.

Page 103.

Azimuth signal is generated by continuous oscillator and is supplied to the azimuth directional antenna. Reference signals are form/shaped with pulse generator and transmit to the omnidirectional antenna. For the coding of reference signals is utilized the encoder of the azimuth channel to which from the rotator come the sequences of momentum/impulse/pulses "35" and "36" during the rotation/revolution of azimuth antenna.

The beacon RSBN-4N provides the transmission of signals the "answer/response of indication" to extension plan position indicator (VIKO). Signals the "answer/response of indication", transmitted by aircraft equipment, are received as the receptor of beacon. From the output/yield of this device the signals are supplied to the decoder where they are decoded. The decoded signals approach IKO for the formation of the mark of aircraft and to the encoder of ranging channel. Here signals are coded by code "relay retort of indication". This code is supplied to the transmitter of ranging channel. Developed thus signal "relay retort of indication" is emitted by the antenna of the transmitter of channel and is received as the antenna of VIKO, placed to KDP. Then this signal is supplied to VIKO for the formation of the mark of aircraft on its screen. Furthermore, as the antenna of VIKO are received the reference signals and signals the "demand of the indications", which are necessary for a formation for the VIKO of reference grid along azimuth and a range.

Beaccn RSBN-4N has remote contrcl frcm KDP. For a relaying from KDP tc the beacon of control signals and frcm beacon to the KDP of signals abcut work of beacon is utilized the equipment for packirg/seal, which makes it possible to transmit all signals on two wires. This equipment provides the transmissicn of signals to distarce tc 30 km.

Basic part of the equipmert - transmitters, receivers, supervisory equipment, decoder, encoders, the control unit of drive - has 100c/c reserve. The start and the disccnnection of each assembly can be conducted from the panel for distantsicnncgoupravleniya cr frcm apparatus beacon.

Work cf beacon is checked by the supervisory equipment, which consists cf contrcl extension receiver and the units of the control of range and azimuth. During the transmittal by supervisory equipment for the signal of "EMERGENCY" is conducted the automatic changeover tc spare assembly. Supervisory equipment is also the unit of dcpuskovogo contrcl, intended for delivery to the panel for the remote control of signal "deterioration in the parameters" during a decrease in the power of transmitters lower than provided by technical specifications level.

Page 104.

In the beaccn of RSBN-4N is improved a series of characteristics. A beacon it has 88 frequency-code channels. The transmitters of radic beaccn are constructed according to the principle of the consecutive

frequency multiplication and amplification of the oscillations of the crystal oscillators (drivers). Therefore the frequency stability of the output oscillations of transmitters completely is determined by quartzes. In receptors for the amplification of high-frequency oscillations are used the travelling-wave tubes. The application/use of these tubes allowed raised the reliability of work of beacon. Its mean time of the mean time between failures taking into account spare assembly and recovery time is 500 hours.

For the instrumentation of the local local aerial lines are developed the simplified azimuth-ranging beacons "beam". The dual root-mean-square measuring error of azimuth on these beacons is 1.5°, while dual root-mean-square measuring error of range -300 m +0.03o/o of measured distance. Is somewhat decreased also the range of beacon. Furthermore, for the sake of simplicity in the beacon the reception of the inquiring signals of aircraft equipment and the emission/radiation of response signals is conducted on the directional azimuth antenna. Thus, the information about range approaches aircraft not continuously, but discretely into those points in time when azimuth antenna is directed toward aircraft. The use of the directional antenna for the transmission of the signals of ranging channel makes it possible to decrease the power of the transmitter of ranging channel and the sensitivity of receptor, which leads to simplification in the beacon. At the same time in beacons "beam" is increased the amount of frequency-code channels to 176.

Besides the examined installed equipment of the type of RSBN-2, are developed and are released by industry the new types of aircraft

equipment cf the azimuth-ranging system: RSBN-2sa, RSBN-P, RSBN-PK. Equipment for types RSBN-2sa and for RSBN-P is transient modification to the more advarceed instrumentation of types BSBN-PK.

Instrumentation of the type "RSBN-2sa" differs from equipment RSBN 2s in terms of the supplementary unit of coupling with aircraft navigaticral computer.

Instrumentation of the type of RSBN-P includes those which were executed cn electron tubes aircraft transmitter the SZD and aircraft receiver decay, which entered in ccntent cf equipment RSBN-2s, and the new, acccmplished/carried out cn semiconductor devices, measuring units of azimuth and range.

Page 105.

In these urits was for the first time used the digital method of the measurement cf azimuth and range. Instrumertation RSBN-P has a communication/ccnnection with navigational computer for trajectory correction and with automatic control system in landing operating mode. In more detail indicated special feature/peculiarities will be examined in connection with equipment for the type of RSBN-PK.

The instrumentation of the type of RSBN-PK provides the measurement cf slant range and azimuth relative to ground beacons of the type cf RSBN-2N and RSBN-4N the delivery of these data tc indicator instruments and into digital and analcg type on-board computers for their correction. Furthermore, it can measure the angular deflections of aircraft from the glisady, assigned with the beacons cf a heading-slope landing system cf the type of PRMG-4, and

determine distance of the landing relay cf range finder. This instrumentaticn is part of the navigaticn-landing ccmplex and therefore in it are provided ccmmunication/connection with different aircraft systems. Equipment RSBN-PK is ccnrected with the navigaticn-landing instrumentation of KURS-MP-2, the radio distance gauge of SDK-67, with course system and the system of air signals, with digital and analog computers and with airborne guidance system. In more detail the questions of aggregaticn are examined in the third secticn cf textbcck.

Fig. 2.28. Block diagram of the instrumentation of RSBN-PK.

Key: (1) the unit of addition.

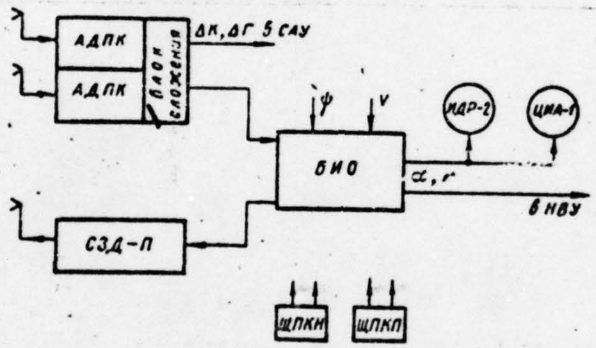


FIG. 2.28.

Page 106.

The simplified block diagram of the instrumentation of RSBN-PK is given in Fig. 2.28. Into its composition enter two receiver of the ADPK, united by the unit of addition, transmitter SZD-P, the measuring unit and final adjustment of ~~Biot~~ BIO, who consists of the measuring unit of azimuth and range, unit of coupling and unit of final adjustment, the panel of switching the channels of the navigation of Sh PKN, the panel of switching the channels of landing Sh PKP, the digital bearing meter of Ts IA-1, two range indicator of the radio station of IDR-2.

All units of equipment for RSBN-PK are executed on semiconductor devices in micromodule performance. Total weight of assembly 68 kg. The amount of frequency-code channels is 88. Accuracy of the measurement of azimuth and range the same as in instrumentation RSBN-2s.

The operating principle of the instrumentation of RSBN-PK consists of the following. During ranging on aircraft the transmitter SZD-P develops the high-frequency coded inquiring signals, synchronized by the trigger pulses, which enter from ~~Biot~~ BIO. The response signals of ground beacon are received as the receivers of ADPK, they are amplified by them, are decoded and are supplied to measuring unit and final adjustments. This unit measures the time interval between the starting and reciprocal momentum/impulse/pulse. For this is utilized the digital measuring circuit, which switches on the crystal oscillator of measuring momentum/impulse/pulses and pulse counter. Pulse generator develops the sequence of

momentum/impulse/pulses with repetition frequency 1 Mhz. one period corresponds 150 m of range. The time lag of reciprocal momentum/impulse/pulse is measured by the calculation of the number of measuring momentum/impulse/pulses, which are placed in the time interval of time lag. The calculation of the number of momentum/impulse/pulses is realized by a 12-bit trigger counter. The jettisoning of this counter is conducted by trigger pulse, and at the torque/moment of the arrival of reciprocal momentum/impulse/pulse the binary code of range is copied from counter into memory unit. Then the code of range is converted into angular value by converter code - voltage - angle and is issued to indicator instrument.

Azimuth determination on aircraft is conducted by the measurement of the time interval between the momentum/impulse/pulse of northern agreement and azimuth momentum/impulse/pulse. For this is utilized digital measuring circuit in B10. To this diagram from receivers enter reference pulses [35] and [36] and azimuth momentum/impulse/pulses. Measuring circuit consists of two counters - rough and precise and pulse generator. To rough counter enter reference pulses [36] and the momentum/impulse/pulse of northern agreement, manufactured into the torque/moment of pulse coincidence "36" and "35". This counter is dumped by the momentum/impulse/pulse of northern agreement and begins to compute the amount of momentum/impulse/pulses "36", that are placed in the time interval of the time lag of azimuth momentum/impulse/pulse.

Page 107.

Thus the rough counter determines the value of azimuth with accuracy 10°.

The precision measurement of azimuth is realized by a precise counter. To this counter enter the momentum/impulse/pulses "36] and the signals of pulse generator. The latter is started by momentum/impulse/pulses "36" and develops the sequence of the measuring momentum/impulse/pulses, the repetition period of which corresponds to angle of 0.02°. The jettisoning of a precise counter is conducted by each momentum/impulse/pulse: "36" and after this counter begins to compute the amount of measuring momentum/impulse/pulses, which are placed in the interval between momentum/impulse/pulse "36" and azimuth momentum/impulse/pulse. Thus a precise counter measures a precise position of aircraft within desyatigradusnogo sector.

After the reception of azimuth momentum/impulse/pulse the measured value of azimuth by rough and precise counters is copied into the pyatnadtsatirazryadnoye trigger memory unit in the form of binary code. Then the binary code of azimuth is converted into angular value with the aid of converter code - voltage - angle and is supplied to indicator instrument.

Work of installed equipment of RSBN-PK with signal conditioning the "answer/response of indication" and in landing attitude they in no way differ from the examined functioning of instrumentation RSBN-2s.

The measuring unit and final adjustment has a communication/connection with course system and the system of the air

signals from which are supplied the values of magnetic heading and airspeed. In ~~Biot~~ BIO is conducted the determiration radial component of airspeed $\dot{V_r}$ (along the line, which connects aircraft and beacon) and azimuth constituting (perpendicular radial velocity V_r) airspeed V. Indicated velocity components are integrated with the short-term signal fading of beacon, providing thereby the delivery of the values of range and azimuth in this case.

The signal of course ψ is utilized also in ~~Biot~~ BIO for the computation of the heading/course angle of the radio beacon Radio Station Course Angle which enters for an indication to the instruments of IKU-1.

The measured by the instrumentation of RSBN-PK instantaneous values of azimuth and range of aircraft are utilized also for the correction of on-board calculators. Therefore the measuring unit and final adjustment has a communication/connection with these calculators. There transmit the measured values of azimuth and range. For digital calculator these values enter polar coordinate system, while to analog they enter in rectangular.

Page 108.

The necessary in this case transformation of polar coordinates into rectangular is realized in ~~Biot~~ BIO.

Equipment RSBN-PK provides with coupling with the instrumentation of KURS-MP-2 and SDK-67 the indication of azimuth and range relative to beacons VOR DME, and also the correction of navigational computers.

In this case the instrumentaticn KURS-MP-2 measures the azimuth to beaccn VOR DME, and SDK-67 - range thus far beaccn. Coupling is realized by means of the communicaticn/connection of the instrumentation of KURS-MP-2 and transceiver of SDK-67 with the measuring urit and final adjustment cf equipment for RSBN-PK. From the measuring device of ~~Biot~~ БІО's range to transmitter SDK-67 enter the trigger pulses. The reciprocal momentum/impulse/pulses of ground beaccn VOR DME, delayed for a period, proporticnal to range, from the receptor cf SDK-67 enter back into the measuring device of ~~Biot~~ БІО's range, prcviding ranging. The measured azimuth enters from the instrumentaticn cf KURS-MP-2 in analog form through selsyn transmissicn. The values of azimuth and range of beacon VOR DME are issued tc the indicator instruments of ~~Ø~~ ПІА-1 and IDR-2, and alsc for the correcticn nazivatsicnnykh calculators along those channels themselves, as in operating mode with beaccns RSBN.

Instrumentation RSBN-PK has the built-in ccntrol. With pushing of kncb "ccntrol" on the bearing meters and range must the conservative values of azimuth 181° and cf range 291.6 km, which testifies tc the normal cperation cf measuring devices.

In new installed equipment of azimuth-ranging system (RSBN-P, RSBN-PK) there is no mode/conditions zero - driving along the predetermined trajectories. This is explained by the fact that now this functicn performs aircraft computers. The problem of installed equipment RSBN is the correcticn of these calculators, for which from equipment RSBN tc calculators are supplied the signals of azimuth and range.

one of the fazhnykh development trends of installed equipment of azimuth-ranging system is an increase in the reliability of its work. The reliability of work of aircraft equipment is related to one of its most important characteristics, which significantly shows up in flight safety. Especially important value acquires the reliability of work of on-board radio navigation instrumentation when it is utilized as part of the automatic control system of the flight of aircraft.

Page 109.

New aircraft equipment of azimuth-ranging system is made with semiconductor devices, which, it is natural, raises its reliability. At the same time this instrumentation is fairly complicated and consists of the large number of radio parts. Breakdown of one cell/element leads to the failure of entire instrumentation. But in spite of the application/use of highly reliable parts and cell/elements the general reliability of one assembly of instrumentation cannot be obtained by very high and is estimated at the mean time of the mean time between failures of the order of several hundreds of hours.

The basic method of an increase in the reliability of radio equipment is its redundancy. When using 100c/c of reserve the failure probability of equipment taking into account reserve is equal to the square of the failure probability of one assembly of equipment. Since the failure probability of one assembly is much less than unity, the indicated dependence leads to a considerable increase in the

reliability of the reserved instrumentation.

Application/use 100o/o of reserve of aircraft equipment leads to increase two times of weight and space of equipment. It is earlier, when on aircraft was applied electron-tube radio equipment, to utilize redundancy virtually was not represented possible due to exaggerated size/dimensions and the weight of equipment. At present because of change to semiconductor devices and a decrease in weight and overall sizes of radio equipment appeared real possibility to raise the reliability of work of aircraft radio equipment by applying spare assemblies.

For an increase in the reliability of work of aircraft equipment of an azimuth-ranging system of the type of RSBN-PK on large aircraft (Tu-144, Tu-154, IL-62) can be utilized the dual assembly of this equipment. In this case in the composition of aircraft equipment of system RSBN will enter two transmitter of SZD-P, two receiver of ADPK and two measuring unit and final adjustment of ~~Bist~~ BIO. In this case redundancy it is possible to realize as follows.

Receptors can be included by the diagram of parallel redundancy (parallel connection with the addition of video outputs) in the manner that this is made in the instrumentation of RSBN-PK (see Fig. 2.28). Transmitters and measuring units it cannot be switched on by the diagram of parallel redundancy because of the ill effect of spare device on basic, which can lead to the disruption of work of instrumentation. Therefore such devices are switched on by the diagram of reserved replacement value, in which spare device is connected to instrumentation instead of that which was refused, and

the latter is disconnected.

Page 110.

By the possible version of the redundancy of transmitters and measuring units it is such. Are utilized two pairs of devices transmitter - measuring unit. During the malfunction of transmitter or measuring unit are disconnected both devices and instead of them it is connected another pair transmitter - measuring unit. However, more effective is the poblochnoye redundancy, when with the failure one device (transmitter or measuring unit) instead of it is connected analogous spare device. In this case the general reliability of instrumentation is raised.

§ 2.9. Basic information about foreign azimuth-ranging radio-navigation systems.

Standard azimuth-ranging system in the countries, which enter the international organization of the civil aviation, is considered system VOR DME, that is the totality of omnirange VOR and ranging system the DME whose relay is established/installed at the same radio navigation point, as the radio beacon is VOR. In the USA and the countries of Western Europe wide distribution obtained also azimuth-ranging system TAKAN ~~Tacan~~, ensuring the higher accuracy of the measurement of azimuth and range, than system VOR DME.

The azimuth-ranging radio-navigation system TAKAN ~~Tacan~~ in the form of

the utilized for navigational measurements parameters of signal is fazc-time/temporary system. Let us examire the operating principle of this system. fazc-time/temporary azimuth-ranging system (Fig. 2.29) it consists of ground-based radio beacon and the aircraft receiving-transmitting and instrumentation. The system provides measurement on the aircraft of distance of the point of the arrangement/permutation of ground-based radio beacon and azimuth of aircraft relative to the meridian of this point. The indicated coordinates are determined on aircraft by processing the response signals of ground beacon, and also its supplementary signals.

Inquiring signals are generated by aircraft transmitter and are the pulse coded high-frequency signals. These signals are emitted by the transmitting antenna and are received on the earth/ground as the antenna of beacon. After amplification by ground-based receiver they enter the transmitter of the beacon which form/shapes the coded high-frequency response signals.

Page 111.

After entering to the antenna of beacon, response signals are emitted into space and are propagated to aircraft.

The receiving-transmitting antenna of beacon is directed in horizontal plane. The radiation pattern of this antenna (Fig. 2.30) has nine lug/lobes 40° wide, but with the different values of the maximums of luj/lobes. This radiation pattern can be considered as imposition on each other of two radiation patterns. one of these

diagrams (dotted line in Fig. 2.30) has one maximum, and the second is 9-lobed.

In work of beacon the radiation pattern of its antenna rotates in horizontal plane with a velocity of 900 r/min or 15 r/s. Since reciprocal momentum/impulse/pulses transmit to aircraft with the aid of the antenna, which has the revolving directional characteristic, the taken by aircraft signals will be modulated in amplitude (Fig. 2.31b).

Fig. 2.29. Block diagram of fazo-time/temporary azimuth-ranging system.

Key: (1) inquiring signals; (2) transmitter; (3) the measuring unit of range; (4) response signals; (5) receiver; (6) the measuring unit of azimuth; (7) the directional antenna; (8) the sensor of reference signals; (9) the oscillator of reference signals.

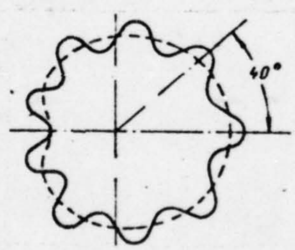


Fig. 2.30. Antenna radiation pattern of ground beacon.

Page 28.

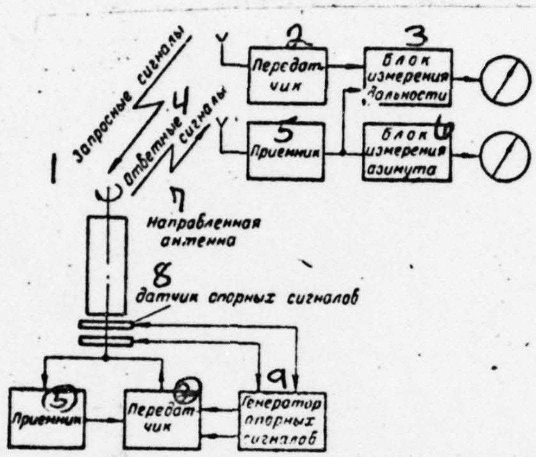


FIG. 2.29.

Page 112.

The law of modulation of the amplitude of the taken momentum/impulse/pulses is determined by the form of the antenna radiation pattern of beacon and by the velocity of its rotation/revolution. Going around the sequences of the momentum/impulse/pulses, accepted by aircraft, has complex form and is the sum of two oscillations 15 and 135 Hz frequency.

MT/ST-76-0659

[redacted]

[redacted]

Page 112 cont.

Fig. 2.31. The time diagrams of fazc-time/temporary azimuth-ranging system.

Key: (1) Hz; (2) supporting/reference.

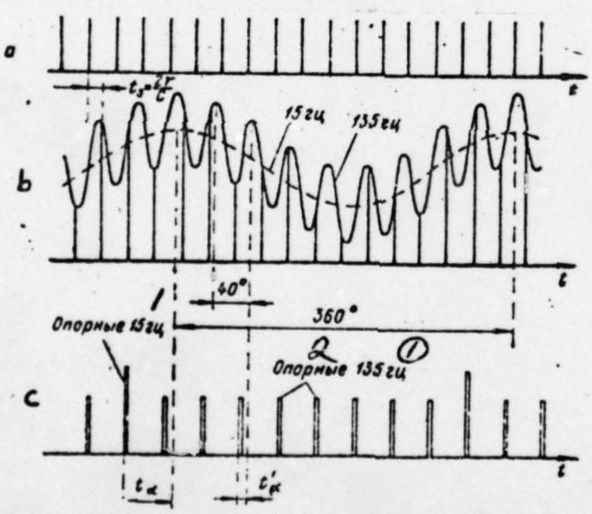


FIG. 2.31.

Go around frequencies 15 Hz arose due to a change in the value of the maximums of the lug/lobes of the antenna radiation pattern of beacon according to the law, shown in Fig. by 2.30 dotted lines. Since this diagram has one maximum, in one turn the amplitude of the taken momentum/impulse/pulses will one time reach the greatest value. This means that going around momentum/impulse/pulses will change with nastotoy 15 Hz. Except one greatest value, in one turn the amplitude of the taken momentum/impulse/pulses will nine times reach the maximum values because the antenna radiation pattern of beacon has nine lug/lobes. For each second the taken signal 135 times reaches maximum, which testifies to a change in the amplitude of reciprocal momentum/impulse/pulses 135 Hz frequency.

Page 113.

Reciprocal momentum/impulse/pulses are amplified on aircraft by receiver and enter after this into the measuring units of range and azimuth. The measuring unit of range automatically measures the time lag of reciprocal momentum/impulse/pulses with respect to the torque/moment of the emission/radiation of inquiring signals from aircraft. This time lag is directly proportional to slant range from aircraft to the ground beacon:

$$t_s = \frac{2r}{c}.$$

The measured time lag reschityvaetsya in unity of range, which is represented by the instrument of range. In order that on the result of ranging would not have an effect the response signals, caused by the demands of other aircraft, in the measuring unit of range were accepted the measures in order that to measuring circuit would enter the only their reciprocal momentum/impulse/pulses, which differ from strange reciprocal momentum/impulse/pulses in terms of the fact that they are synchronous with interrogation pulses, i.e., appear in each repetition period at just one place.

The measuring unit of azimuth automatically measures the azimuth of aircraft relative to the meridian of the place of the arrangement/permutation of ground-based radio beacon. The measurement of azimuth is based on the dependence of the initial envelope phase sequences momentum/impulse/pulses on the azimuth of aircraft. If aircraft is located on certain azimuth α, then the taken momentum/impulse/pulses will achieve/reach the greatest value through time lag t_a with respect to the torque/moment of the passage of northern direction by the greatest lug/lobe of the antenna radiation pattern of beacon. This is connected with the fact that to radiation pattern it is necessary to turn itself to angle α, before the the greatest lug/lobe will be oriented toward aircraft. In this case the time lag is equal

$$t_a = \frac{\alpha}{\Omega}.$$

where $\Omega = 2\pi F$ - the angular rate of rotation of the digrammy of directivity;

$F = 15$ r/s - the amount of turns per unit time.

The initial envelope phase frequency 15 Hz is equal to $\varphi_0 = 2\pi F \cdot t_1 = \alpha$. As it shows the last/latter equation, the initial envelope phase frequency 15 Hz is equal to the azimuth of aircraft. It changes by 360° during a change in the azimuth to the same value, i.e., to each degree of a change in the phase corresponds one degree of a change in the azimuth of aircraft.

Page 114.

The initial envelope phase frequency 135 Hz changes nine times faster. It changes by 360° during a change in the azimuth to 40°, i.e., to the angle between two adjacent lug/lobes of radiation pattern. Each degree of a change in the initial envelope phase frequency 135 Hz corresponds a change in the azimuth to angle only 1/9°. For this reason ~~on for~~ from the ~~going around~~ envelope of frequency 135 Hz the azimuth can be measured more accurately than ~~on the going around~~ from the envelope of frequency 15 Hz. At the same time, the unambiguous measurement of azimuth is possible only from the envelope of frequency of 15 Hz.

The momentum/impulse/pulses, which entered from receiver to the measuring unit of azimuth, are supplied to two filters, tuned to frequencies 15 and 135 Hz. By these filters are separate/liberated the going around sequences of the momentum/impulse/pulses of the beacon of frequencies 15 and 135 Hz. For the measurement of azimuth

it is necessary tc determine the initial phases cf these oscillations.

For the measurement of the initial phase of signal it is necessary tc fix the zero time reference which must be connected with the determined pcsitions of the antenna radiation pattern of beacon. For this purpcse to aircraft frcm ground beacon transmit the reference signals.

The fcrmaticn of reference signals on beacon is conducted as follcws. On the axis of the rctation/revcluticn of antenna are two rings, on cne of which is established/installed one contact, while on the second - nine evenly arranged/located frcm circumference contacts. With the rings are ccnnected twc slip ring, on which during the rotation/revoluticn of antenna appear the mcmentum/impulse/pulses. During one slip ring will be fcrmed the sequence of momentum/impulse/pulses 15 Hz frequency (1 mcmentum/impulse/pulse in each turn cf antenna), while cn another is fcrmed the sequence cf momentum/impulse/pulses 135 Hz frequency (9 momentum/impulse/pulses in each turn of antenna). Rings are oriented cn the axis of the rctation/revcluticn of antenna so that the mcmentum/impulse/pulses of frequency 15 Hz are fcrm/shaped into thcse pcints in time when past the ncrthern direction it passes the greatest lug/lobe of radiation pattern. The mcmentum/impulse/pulses of frequency 135 Hz appear when toward ncrth are directed the maximums cf each lug/lobe of radiation pattern. The examined mcmentum/impulse/pulses are utilized as supporting/reference (Fig. 2.31c).

Reference pulses transmit to aircraft the information about the zero time reference during the measurement cf the initial envelope

phase frequency 15 Hz. The reference momentum/impulse/pulses of frequency 135 Hz are utilized on aircraft during the measurement of the initial envelope phase frequency 135 Hz.

In order that on the aircraft reference pulses it was possible to separate/liberate from the reciprocal, they are coded by another code.

Page 115.

Furthermore, the codes of the reference pulses of frequencies 15 and 135 Hz are distinguished between themselves, which makes it possible to divide on aircraft these signals. The coding of reference signals is conducted in the oscillator of reference signals, whereupon they with the aid of common/general/total transmitter are emitted to aircraft at the frequency of response signals.

The measuring unit of azimuth has two channel - rough and precise, which consecutively work in the search modes and tracking. First in search mode is switched on the rough channel, which measures the initial envelope phase frequency 15 Hz. As a result of this unambiguously is determined the azimuth of aircraft, but with low accuracy. On completion of search mode automatically is switched on the mode/conditions of the tracking in which works a precise channel. This channel measures the initial envelope phase frequency 135 Hz and according to it accurately is determined the azimuth of aircraft.

The special feature/peculiarity of the examined fazo-time/temporary azimuth-ranging system is the fact that in it one and the same pulse signals are utilized twice - for the measurement of

distance and measurement of azimuth. Use in the azimuth part of the system of pulse signals has an advantage in comparison with the use of continuous signals. With pulse signals considerably descends the effect of the ground features on the accuracy of the measurements of azimuth, the propagation time of signals from which differs from the propagation time of the forward signals of beacon by the value, greater than pulse duration. With this straight line and re-emitted signals they are not superimposed one on top of the other, but they follow each other (Fig. 2.32). The value of the forward signal is considerably more than re-emitted one. In receptor on aircraft is utilized the automatic gain control, which works at peak signal, which suppresses weak signals.

Fig. 2.32. To the explanation of the effect of the ground features when using pulse signals.

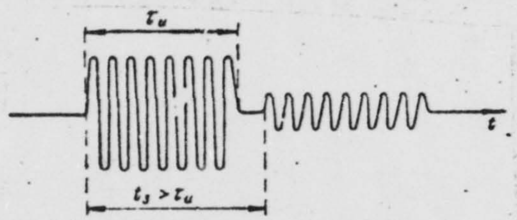


FIG. 2.32.

Page 116.

Therefore envelope phase forward signals in practice does not depend on such re-emissions. During continuous emission/radiation would take place the addition of straight line and re-emitted signals and the phase of the resulting oscillation it would differ from the phase of forward signal, which would lead to measuring error.

System "Tacan" works in VHF range at frequencies 960-1215 Mhz. Its range is restricted to line-of-sight distance and therefore system it is utilized as system of short-range navigation. The maximum range of action is 360 km at flight altitude 10,000 m. The dual root-mean-square measuring error of range is approximately 0.2 miles. The accuracy of the measurement of azimuth is sufficiently high. During the arrangement/permutation of beacon in favorable locality the dual root-mean-square measuring error of azimuth is approximately 0.2-0.4°.

Page 117.

Chapter 3.

RANGE-DIFFERENCE ~~DIFFERENTIAL RANGING RADIO~~ NAVIGATION SYSTEMS.

§ 3.1. General information.

Differential ranging radio-navigation systems received wide acceptance during the last/latter three decades. The operating regions of these systems cover/coat the large part of the dry land and the considerable part of the water surface, but in blizhyshiye years, apparently, by them will be overlapped entire terrestial globe.

The advantages of the differential ranging RNS:

- the long range of action;

- high accuracy;

- the unlimited capacity;

- the relative simplicity of installed equipment they become especially noticeable during the solution of the problems of remote air and marine navigation.

For providing a long range of action these systems work on the middle, long and very long waves of SDV. When using radio waves the SDV of range, the conditions of propagation of which are most favorable, the range RNS can reach 8000-10000 km, also, in order above our planet to create continuous navigational field, it will be required a total of 8-10 ground stations.

Scientific principles and the principles of the tabcty of differential ranging systems were developed by our Soviet scientists under the management/manual of academicians L. I. Mandelstam and N. D. Papaleksi in period of 1930-1940. The materials of these investigations widely were published in periodicals, and the most important results were shielded by author's certificates in 1933 ("phase probe"). On this principle in the Soviet Union they created the differential ranging system of "Koordinatov" with continuous

radic-wave emissicn, in which the measurements cf a difference in the distances were realized by the measurement cf a phase difference.

Page 118.

Later was developed the more advanceed radic engineering system of the high accuracy of RSVT-1.

In England on the same principle in 1944 was developed the system "sounding board", which obtained propagaticr mainly in Western Europe and the northern Atlantic where it works more than 20 ground stations. The system "scunding board" works at frequencies 70-150 kHz and provides range under the daytime conditions above the sea to 900 km, but at night range decreases tc 500 km due to decrease in the accuracy under the effect cf sky waves. The accuracy of position finding depends on distance and directicn and vary within the range cf several dozens tc several hundreds of meters.

In the USA during many years are carried cut research works and it is develop/processed system "omega" at very lcw frequencies in the range 10-14 kHz with the distances between ground stations tc 5000-8000 km. The calculations and experimental data show that the potential accuracy of position finding under daytime conditicns at maximum distances is characterized by the mean square error of the order of one kilcmeter.

Along with creation and introducticn into the practice of phase differential ranging systems the continuous emission/radiaticn are develcped and widely will be utilized systems with pulse

emission/radiaticn. In such systems the difference in the distances is determined by the measurement of a time difference the reception of the signals, obtained aboard the aircraft from two ground-based radio navigation points. Therefore them they call time/temporary.

One of the first systems of this type was the created in the USA in 1942 system loran (Long range navigation), subsequently obtained designation Loran-A. Pulse differential ranging system Loran-A works at frequencies 1750-1950 kHz by momentum/impulse/pulses by duration 40 μs, which makes it possible to separately accept aboard signals from ground stations on surface and sky waves. With the reception of ground waves by day the range above the sea reaches 1100-1400 km, and above the dry land in connection with an increase in the attenuation range it decreases to 400-600 km. At night range decreases 1.5-2 times due to an increase in the level of atmospherics on this frequency band. The error in determination of place from izmeyushchimsya data is obtained about 0.5c/c from distance.

Page 119.

When using sky waves at night the range of system can reach 2500 km, but the accuracy of position finding descends approximately 2 times.

At present in all world it is counted more than 60 working stations Loran-A, arrange/located, mainly, in the USA, in Canada, Japan and Western Europe, in the areas of the most lively navigation and flights of aviation, but installed equipment is establish/installed on the aircraft of all airlines, which operate the

international and domestic airlines.

At the same time frem the preceding information it is evident that the basic indices of system Loran-A: the accuracy and the range to a great degree depend on a change in the conditions of the radiowave propagation of working range, of time of days and character of the underlying surface. In connection with this in the USA into 1944-45 were initiated works on the use of lower frequencies for the creation of the pulse differential ranging systems which continued about 15 years. As a result of these works is created the system loran-loran-S, which works in the range of frequencies 90-110 kHz, to a considerable degree free from the indicated previously deficiency/lacks. Analogous works were carried out, also, in the Soviet Union, which made it possible to create the at first radio engineering system of long-range navigation of the type of RSDN, and then on its principle to develop new, more advanceed. In systems of the type ~~loran~~ Loran-S are applied the combined determinations of a difference in the distances. The preliminary rough determination of this difference is realized by the measurement of a time difference the reception of two signals, which enter from ground stations, and then is carried out its precise determination by the measurement of a phase difference. Therefore such systems are related to that which was combined fazo-time/temporary type systems, which make it possible to obtain a difference in the distances unambiguously, also, with high precision.

Pulsing makes it possible to divide the reception of the surface and sky waves which arrive into the point of reception with different

time lag. When using ground waves in the daytime above the sea the range of such systems, which have the radiated power on the order of 100 kW, reaches 2500 km. At night range descends to 1800 km. During propagation above the dry land the range decreases approximately on 400 km. Accuracy of position finding - on the order of 300 m, and at maximum ranges - about 1000 m.

It is possible to utilize for navigational measurements also sky waves on ranges to 3300 km, besides the periods of rise and sunset, but in this case accuracy descends approximately 10 times.

Page 120.

Operate themselves at present about 30 ground stations of system ~~loran~~-Loran-S. In connection with the positive results of the operation of new system now are carried out the modifications of ground stations Loran-A by the setting up on them of the supplementary transmitters, which work at frequencies ~~Loran~~-Loran-S. In this case is formed transient system Loran-~~ace~~ AS, that works at two frequencies with its subsequent translation/conversion completely into mode/conditions ~~loran~~-Loran-S.

The important advantage of low-frequency systems is the fact that the radio waves of these ranges during propagation above the sea sufficiently deeply penetrate the sea water, which makes it possible for underwater ships to obtain navigational information with high accuracy without floating to surface.

From survey/coverage it is evident that operate themselves at

present the differential ranging systems of three basic types:

1. Phase RNS with continuous emission/radiation.
2. Time/temporary RNS with pulse emission/radiation.
3. fazo-time/temporary RNS.

The operating principles of these systems are examined in the subsequent paragraphs of the present chapter.

§ 3.2. Operating principles of phase differential ranging systems.

For the creation of phase differential ranging system at two points surpress surfaces of A and B establish/install the transmitting radio stations with the nondirectional continuous emission/radiation of high-frequency oscillations (Fig. 3.1a). The distance between ground stations r_{AB}, call base, is selected several dozen times more the wavelength of the emitted oscillations. Each of the ground stations creates in space electromagnetic field e_A and e_B :

$$e_A = E_{Am}\cos(\omega_A t + \varphi_{OA}); \quad e_B = E_{Bm}\cos(\omega_B t + \varphi_{OB}). \tag{3.1}$$

where E_{Am} and E_{Bm} are amplitudes of electric intensity;

ω_A and ω_B - the carrier frequencies of the emitted oscillations;

φ_{OA} and φ_{OB} - the initial phases of these oscillations.

Transmitters in points A and B work strictly in concord between themselves so that during entire operating time is provided the

equality of carrier frequencies and initial phases:

(3.2).
$$\omega_A = \omega_B = \omega;$$
$$\varphi_{OA} = \varphi_{OB} = \varphi_O.$$

Page 121.

For this purpose on ground stations are establish/installed the special matching devices.

From radio engineering are known the following relationships:

$\omega = 2\pi f$, where f is known oscillation frequency;

$f = 1/T$, where T is known the oscillatory period of oscillations;

$\lambda = cT$, where c is known velocity of propagation a λ is a wavelength.

Hence $\omega = 2\pi c/\lambda$.

It is known also that in the process of radiowave propagation at the final velocity occurs the phase lag: during propagation up to the distance, equal to wavelength λ the phase of oscillations delays on 2π, and during propagation to distance, equal r, the phase of oscillations delays to value φ which is located from the relationship:

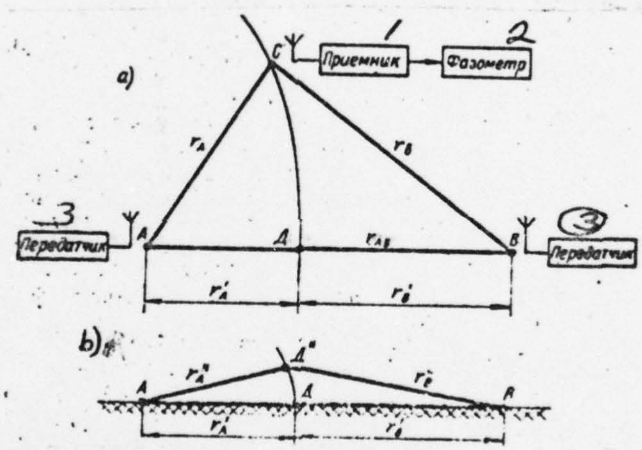
$$\frac{\varphi}{2\pi} = \frac{r}{\lambda},$$

whence we obtain the value of the phase lag of oscillations at the propagation:

(3.3)
$$\varphi = \frac{2\pi}{\lambda} r.$$

Fig. 3.1. Operating principle of phase differential ranging system.

Key: (1) receiver; (2) phasemeter; (3) transmitter.



Page 122.

Let us visualize that at point C, which is located at a distance r_A from station A and at a distance r_B from point B, is conducted the reception of the oscillations, emitted by stations A and B.

Then the phases of the adopted oscillations will be:

$$\varphi_A = \omega t + \varphi_0 - \frac{2\pi}{\lambda} r_A;$$
$$\varphi_B = \omega t + \varphi_0 - \frac{2\pi}{\lambda} r_B. \quad (3.4).$$

A phase difference of the taken oscillations will compose the value:

$$\varphi = \varphi_A - \varphi_B = \frac{2\pi}{\lambda}(r_B - r_A). \quad (3.5).$$

Thus, is establish/installed the communication/connection between a phase difference of the oscillations, taken at point C, and a difference in the distances r_B and r_A, passed by radio waves from the ground stations A and B. A phase difference ϕ became the carrier of navigational data. If we are move ourselves on plane, retaining by constant the measured phase difference φ = const, then in this case a difference in the distances of point A and B will be retained also constant: $r_B - r_A = \text{const}$, a the line of equal differences in the distances on plane to two record/fixed points on this ploskosti (foci) will be hyperbola.

By assigning the different value of a phase difference, it is possible to construct the family of hyperbolas relative to foci A and B.

This will be the family of lines of position in the form of the lines of equal differences in the distances LBFF, formed the pair of the ground stations A and B on the plane of earth.

Shsli tc examine space above this plane in the determined altitude range, then to condition $r_B - r_A$ =const will correspond the family of the surfaces of the positions each of which is formed by the rotation/revolution of hyperbola around base line r_{AB} (Fig. 3.1b).

For using the formed family of lines of position aboard of flight vehicle it is necessary to have the receptor, capable to separately pick up signal of two continuously radiating ground stations, and the measuring device, suitable for the measurement of a phase difference of the taken oscillations.

Page 123.

If both ground stations are continuously emit the fluctuations of identical frequency, then these signals slozhatsya in space, form one total fluctuation and the separate reception of stations A and B it will be physically nezovmozhen. For providing a possibility of separate reception for the ground stations A and B it is necessary to work at different frequencies ω_A and ω_B, which are located in the rational (integral) relationship:

$$n\omega_A = m\omega_B;$$

$$\omega_A = \frac{m}{n}\omega_B.$$

where n and m are integers.

Accepted aboard the signals of the ground stations A and B enter the appropriate frequency channels of the receptor, tuned to frequencies ω_A and ω_B . After amplification is conducted the multiplication of these frequencies by n and m, as a result of which both fluctuations are led to standard frequency: $n\omega_A = m\omega_B = \omega_C$.

Then both fluctuations of already identical frequency (standard frequency ω_C) are supplied to measuring the equipment/device-phasemeter where is conducted the measurement of a phase difference, is determined the corresponding to it difference in the distances and is found the line of position of flight vehicle in the form of the line of equal differences in the distances LBRR.

This method of the separation of the signals of ground stations is called frequency (frequency selection).

For this purpose it is possible to use the method of time sharing signals (time selection). In this case the ground stations A and B, working at identical frequencies, send their signals in the form of groups out of 5-8 momentum/impulse/pulses, forming one or the other code combination, appropriated to each station. Utilizing code sign/criteria of the emitted signals (number of momentum/impulse/pulses, their duration, time intervals between them), possible to divide the signals of the ground stations A and B in terms of the appropriate channels of on-board receptor, then to stretch them

into continuous fluctuations and to measure the phase difference, which accumulated in the process of propagation. Both methods - frequency and time/temporary - find at present wide application in practice.

Let us examine in more detail established/installed communication/connection between a phase difference ϕ the taken signals and a difference in the distances of the point of reception from the ground stations A and B.

Page 124.

For this formula (3.5) let us record in another form:

$$r_B - r_A = \frac{\lambda}{2\pi}\varphi. \quad (3.6)$$

Let us take any point D, which lies on base d between ground stations (Fig. 3.2). Then distances r_A and r_B can be presented in the form:

$$r_A = \frac{d}{2} - x;$$
$$r_B = \frac{d}{2} + x.$$

A difference in the distances will be equal to:

(3.7). $r_B - r_A = 2x.$

By substituting it in formula (3.6), we will obtain:

(3.8). $x = \frac{\lambda}{4\pi}\varphi.$

When a phase difference $\phi = 0$, $x = 0$, then

$$r_A = r_B = \frac{d}{2}$$

and the selected by us point D will be located on the middle of base d.

Fig. 3.2. Family of the lines of position of phase differential ranging system.

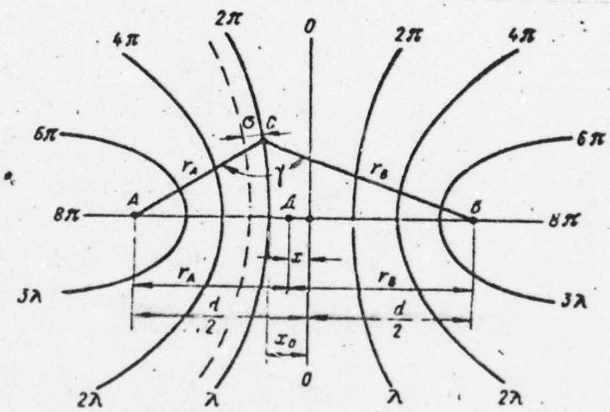


FIG. 3.2.

Page 125.

If this point is moved along the perpendicular, restored/reduced from the middle of base, then in all points of this perpendicular a difference in the distances and a phase difference will be identical and equal to zero.

We will now move point D along base towards station A. With this will change value x and the connected with it value ϕ. Let a phase difference achieve value 2π, and the corresponding to this value value x will become equal to x_0. On the basis (3.8) we will obtain:

$$x_0 = \frac{\lambda}{4\pi} 2\pi - \frac{\lambda}{2}, \quad (3.9)$$

a a difference in the distances

$$r_B - r_A = \lambda. \quad (3.10)$$

Through the obtained point on base passes the hyperbola, all points of which have an identical difference in the distances, equal to wavelength λ, and a difference once 2π.

During further shift to the side of station A will be initiated the second cycle of a change in the phase difference. Through the cut will be found the point on the base past which passes the hyperbola

with a difference in the distances 2λ and a phase difference 4π, then hyperbola 3λ and 6π etc. Whole space between stations will be divided by these lines into a series of bands (the "phase path/tracks") whose width on base is equal to the half of wavelength, and with distance this width will grow/rise. Within each phase path/track during a change in the difference in the distances the measured phase difference czmenyaetsya from zero to 360°, and upon transition to another path/track, the readings will be repeated, will appear the ambiguity (multiformity) of reading. The number of such path/tracks on base d will be equal to:

$$n_1 = \frac{d}{x_0} = \frac{2d}{\lambda}. \quad (3.11)$$

Each measured value of a phase difference within each path/track will correspond the hyperbole trace of position - LRRR. However, the number of these lines depends on the accuracy of measurements.

MT/ST-76-0659

[redacted]

[redacted]

Page 125 cont.

Actually, phase interval, and it means and the distance between adjacent lines of position they must be not less than measuring errors. If the mean square error of the measurements of a phase difference is equal to σ_φ, that within the limits of phase path/track it is possible to distinguish n_2 of lines of position (with probability 68o/o):

$$n_2 = \frac{360}{\sigma_\varphi^\circ}. \quad (3.12)$$

Page 126.

The total number of lines of position which can be obtained from the pair of the ground stations of phase system, it is equal to:

$$N = n_1 n_2 = \frac{2d}{\lambda}\,\frac{360}{\sigma_\varphi^\circ} = \frac{720}{\sigma_\varphi^\circ}\,\frac{d}{\lambda}. \quad (3.13)$$

This number depends on the accuracy of measurements and ratio of the length of base to wavelength.

If $d/\lambda = 50$, and the mean square error of measurements composes 1/100 phase cycles, i.e. $\sigma_\varphi^\circ = 3{,}6^\circ$, that

$$N = \frac{720}{3{,}6}\,50 = 10000.$$

If we from the center of base construct circle with radius of $r > d/2$, then the branches of hyperbolas will cross it in 2N places, on the average through

$$\frac{360}{2N}=\frac{360}{2\cdot 10\,000}\approx 0{,}02^\circ,$$

that it shows to the high accuracy which can be obtained from phase type differential ranging systems.

Let us estimate the accuracy of the determination of lines of position in these systems. For this purpose let us differentiate both parts of expression (3.6):

$$d(r_B-r_A)=d\left(\frac{\lambda}{2\pi}\varphi\right)$$

let us pass to the finite increments

$$\Delta r=\frac{\lambda}{2\pi}\Delta\varphi. \qquad (3.14).$$

Value $\Delta\varphi$ represents by itself the measuring error of a phase difference, while value Δr - the caused by this measuring error of a difference in the distances. Analogous relationship will be also between the root mean square values of these errors:

$$\sigma_r = \frac{\lambda}{2\pi}\sigma_\varphi. \quad (3.15)$$

As a result will be determined the erroneous hyperbola, displaced to relatively true on the linear value σ (see Fig. 3.2), which is determined from the formula:

$$\sigma = \frac{\sigma_r}{2\sin\frac{\gamma}{2}}, \quad (3.16)$$

where γ is an angle of base at point C, where are conducted these determinations.

Page 127.

Substituting here values σ_r from (3.15), we obtain

$$\sigma = \frac{\lambda\sigma_\varphi}{4\pi\sin\frac{\gamma}{2}}, \quad (3.17)$$

or

$$\sigma = \frac{\lambda\sigma_\varphi^\circ}{720\sin\frac{\gamma}{2}}. \quad (3.17a)$$

From these formulas is visible the dependence of accuracy on range as

a result of the divergence of hyperbolas. During distance from base, the angle γ decreases and the linear bias of hyperbola increases. The highest accuracy is obtained on the base where γ = 180° and

(3.18) $$s=\frac{\lambda\sigma_\varphi}{4\pi},$$

or

(3.18a). $$\sigma=\frac{\lambda\sigma_\varphi^\circ}{720}.$$

Each degree of the error in measurement of a phase difference causes the error in the determination of line of position of base velichincyu 1/720 wavelengths. Now let us examine the dependence of accuracy on direction during large distances from base, when distance r ≫ d (Fig. 3.3). Under these conditions the branch of hyperbola differs little from straight line - the assimptoty, angular position of which is characterized by angle α. The directions of radiowave propagation from ground stations into the point of reception we will consider approximately parallel, then a difference in the distances is equal to:

(3.19). $$r_B-r_A=d\sin\alpha.$$

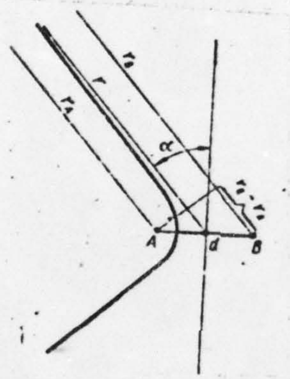
By substituting this expression in formula (3.6), we will obtain

$$d\sin\alpha = \frac{\lambda}{2\pi}\varphi. \quad (3.20)$$

whence

$$\sin\alpha = \frac{\varphi}{2\pi\frac{d}{\lambda}}.$$

Fig. 3.3. Accuracy of the determination of line of position at large distance from base.



Page 128.

Differentiating the last/latter expression we find:

$$\cos\alpha \cdot d\alpha = \frac{d\varphi}{2\pi \frac{d}{\lambda}};$$

$$d\alpha = \frac{d\varphi}{2\pi \frac{d}{\lambda} \cos\alpha}.$$

Passing over to the finite increments, we obtain

$$(3.22). \qquad \Delta\alpha = \frac{\Delta\varphi}{2\pi \frac{d}{\lambda} \cos\alpha}.$$

The last/latter formula shows the value of the angular displacement of hyperbola $\Delta\alpha$ (it is more precise than the assimptoty to it) with the error in measurements of a phase difference $\Delta\varphi$. Analogous relationship will occur also between the root mean square values of these errors:

$$(3.23) \qquad \sigma_\alpha = \frac{\sigma_\varphi}{2\pi \frac{d}{\lambda} \cos\alpha}$$

or

(3.24).
$$\sigma_{\alpha}^{\circ}=\frac{\sigma_{\varphi}^{\circ}}{2\pi\frac{d}{\lambda}\cos\alpha}.$$

Figure 3.4 gives two curves, that show the dependence of the angular displacement of hyperbola σ_{α}° from their angular position for the bases of different relative length.

Fig. 3.4. Curve/graphs of the dependence of errors on the angular position of aircraft.

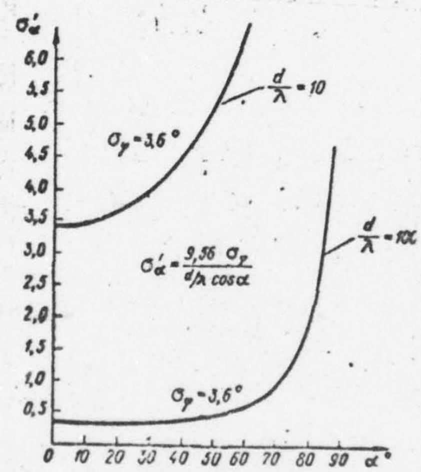


FIG. 3.4.

Page 129.

As can be seen from formulas (3.23) and (3.24), and also from the curve/graphs of Fig. 3.4 phase differential ranging systems have the highest accuracy about standard to the middle of base, equal to

$$\sigma_{\alpha} = \frac{\sigma_{\varphi}}{2\pi\frac{d}{\lambda}} \quad (3.25)$$

or

$$\sigma_{\alpha}^{\circ} = \frac{\sigma_{\varphi}^{\circ}}{2\pi\frac{d}{\lambda}}. \quad (3.26)$$

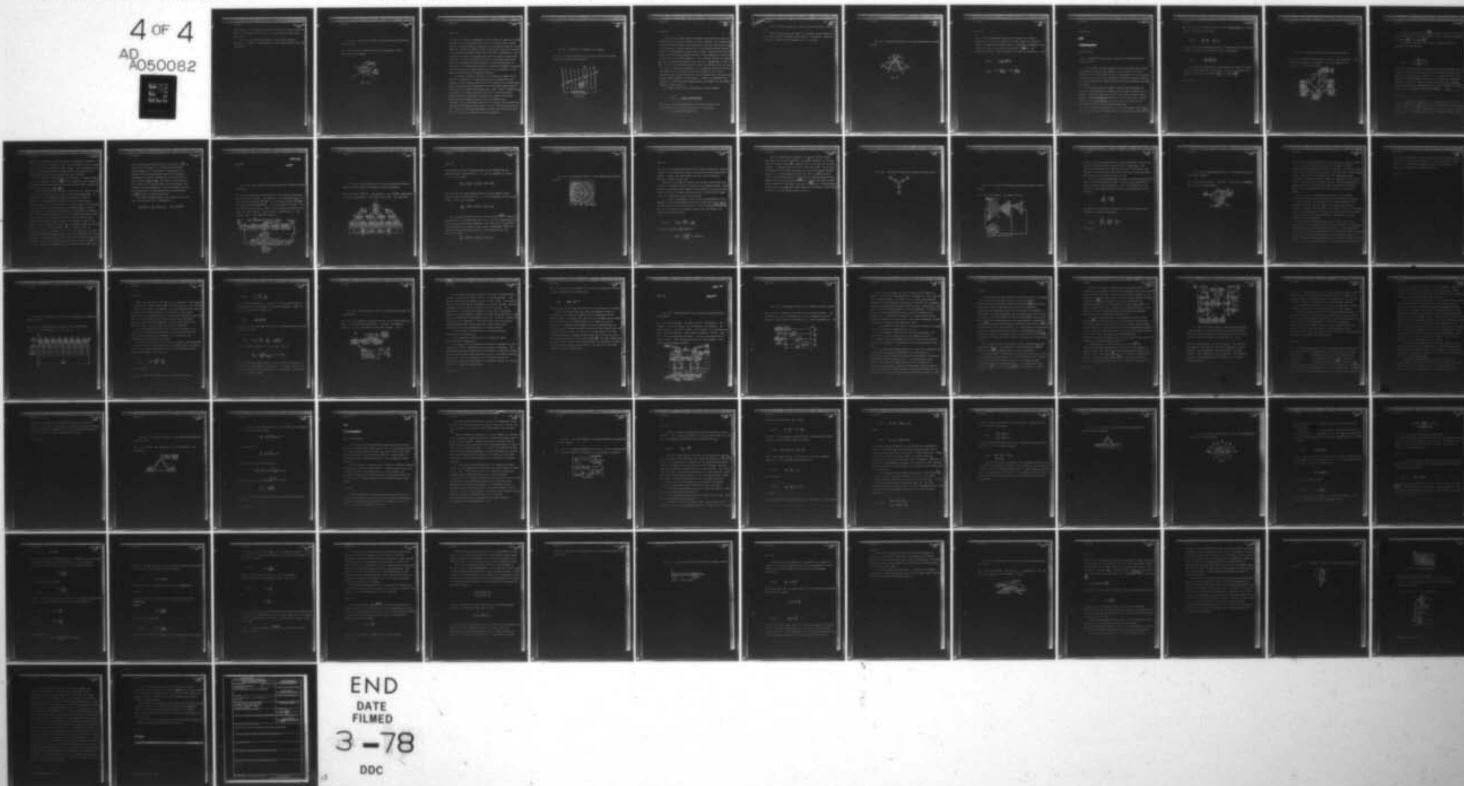
At the relative length of base $d/\lambda = 10$ and the with error of phase measurements $\sigma_{\varphi} = \frac{1}{100}$ phase cycle (3.6°) the angular displacement of hyperbola will compose the value:

$$\sigma_{\alpha} = \frac{3,6}{2\pi \cdot 10} = 0,057° = 3,45'.$$

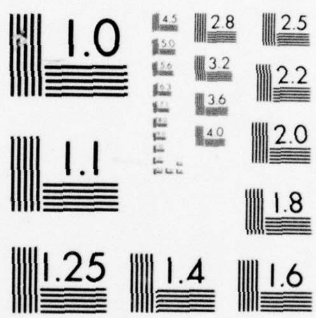
During deflection from standard, the accuracy of the determination of lines of position decreases and, when angle α becomes equal to 60°, error increases double. A further increase in the angle will cause the rapid increase of error; therefore sector within limits of ± 60°

AD-A050 082   FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO   F/G 17/7
RADIO EQUIPMENT FOR AIR NAVIGATION,(U)
MAY 76 G P ASTAFYEV, V V GRACHEV, A S KULCHIY
UNCLASSIFIED   FTD-ID(RS)T-0659-76   NL

4 OF 4
AD A050082



END
DATE FILMED
3-78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

from standard it is accepted to consider worker, but sector from 60 to 90° is not recommended to use due to a rapid decay in the accuracy (Fig. 3.5).

Since in the operating principle of phase RNS is laid the ambiguity in reading, it is necessary to take special measures for its elimination.

Fig. 3.5. Sectors of the high and lowered/reduced accuracy in phase systems.

Key: (1) the sector of high accuracy; (2) the sector of the lowered/reduced accuracy.

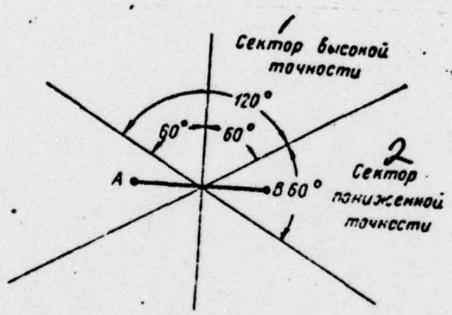


FIG. 3.5.

Page 130.

The easiest method of unequivocal obtaining lines of position in phase systems is the calculation of the number of complete phase cycles. For this measuring device is supplied with the counter with the aid of which is recorded the number of phase path/tracks, passed by aircraft in the process of flight enroute, and therefore at any point in time is known the number of the phase path/track on which is located the aircraft. For the elimination of ambiguity in reading with use by system is required the initial joining of aircraft indicators to locality and the subsequent continuous tracking the number of complete phase cycles, which requires the provision for a continuity in the work of ground-based and installed equipment.

In order to eliminate the need for the initial joining and to raise the reliability of obtaining unequivocal reading for phase systems, besides precise grids of lines of position, are created also coarse grids with phase path/tracks ("by the zones") whose width is greater than of precise 20-30 times (Fig. 3.6). First is conductn the measurement of a phase difference according to the rough scale which it makes it possible to determine the number of the phase path/track of a precise grid, and then they measure $\varphi_{\text{точн}}$ according to precision dial, which makes it possible to unambiguously and accurately determine the line of position. The determination of the position of the phase path/track of coarse grid can be executed with the aid of other means for rough orientation.

Fig. 3.6. Elimination of ambiguity in reading.

Key: (1) the phase path/track of a precise grid; (2) the phase path/track of coarse grid ("zone").

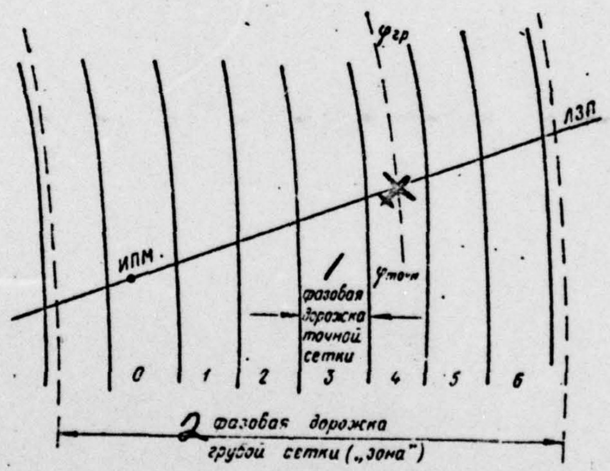


FIG. 3.6.

Page 131.

, until now, we spoke about the methods of obtaining the line of position with the aid of the pair of ground stations. For determining the position of aircraft it is necessary to have two cross lines, that it is possible to ensure with the aid of two pairs of ground stations (3.7), of generatrices two bases A_1B_1 and A_2B_2. Such two bases can be formed by three ground stations because of the association of stations A_1 and A_2 into the single station A. Then pair AB_1 creates the family of lines of position on base d_1, and pair AB_2 - respectively on base d_2. The point of intersection of two lines of position of LP_1 and LP_2 will give the position of aircraft. The accuracy of position finding will depend on the accuracy of the determination of the lines of position σ_1 and σ_2 and of the value of the angle of their intersection (angle between tangents to these lines). Usually in navigation the accuracy of position finding approximately is estimated at the middle quadratic radial error r.

The value of this error is calculated from the formula:

$$(3.27) \qquad r = \frac{1}{\sin\psi}\sqrt{\sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2\cos\psi},$$

where σ_1, σ_2 it are calculated the mean square errors of the determination of the lines of position of LP_1 and LP_2;

ρ - the correlation coefficient;

Ψ - the intersection angle of the lines of position of LP_1 and LP_2.

Value r characterizes the radius of a circle, the probability of the determination of aircraft within which P = 0.63-0.68. Errors σ_1 and σ_2 are calculated from formulas (3.17) or (3.17a).

Fig. 3.7. Principle of position finding by differential ranging methods.

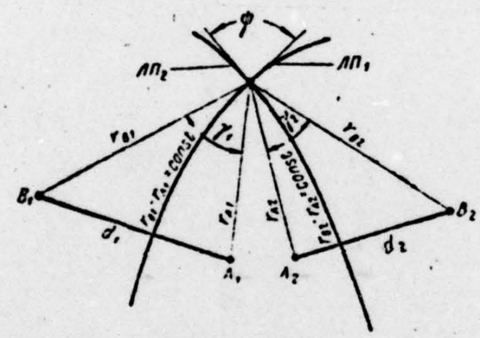


FIG. 3.7.

Page 132.

Their value is determined by the measuring errors of a phase difference $\sigma_{\varphi 1}$ and $\sigma_{\varphi 2}$, which to a certair degree are connected between themselves and are not mutually independent; therefore in the general case the coefficient of correlation ρ ($\neq$ 0. For independent errors in the determination of lines of position $\rho = 0$ and

(3.28) $$r = \frac{1}{\sin\psi}\sqrt{\sigma_1^2+\sigma_2^2};$$

(3.29) $$\sigma_1 = -\frac{\sigma_{r1}}{2\sin\frac{\gamma_1}{2}}, \quad \sigma_2 = \frac{\sigma_{r2}}{2\sin\frac{\gamma_2}{2}}.$$

MT/ST-76-0659

[redacted]

[redacted]

Pages 132-161.

§ 3.3. Ground-based and aircraft equipment of phase differential ranging systems.

Let us examine the most widely accepted in Western Europe phase differential ranging system "sounding board", which works on the principle of the phase probe of Mandelstam-papaleksi. In this system is applied the method of the frequency selection of received signals, and the measurement of a phase difference they are carried out on high frequency.

The ground equipment of system "scunding board" consists of three, and sometimes four in concord working ground stations one of which is called driving, and the others by driven. Master station assigns common/~~general/total~~ operating mode, and each slave station matches the mode/~~conditions~~ of its work with that which drive on frequency and phase of the emitted fluctuations.

Let us examine the system of three ground stations, presented in Fig. 3.8, consisting of master station A and two slave stations ~~A~~ B and

Д. The carrier frequencies of all stations ω_A, ω_B, and $\omega_Д$ are related between themselves as integers:

$$\frac{\omega_A}{\omega_B} = \frac{m}{n}; \quad \frac{\omega_A}{\omega_Д} = \frac{l}{m} \tag{3.30}$$

that it allows subsequently with the aid of multipliers and frequency dividers to lead them to overall standard frequencies:

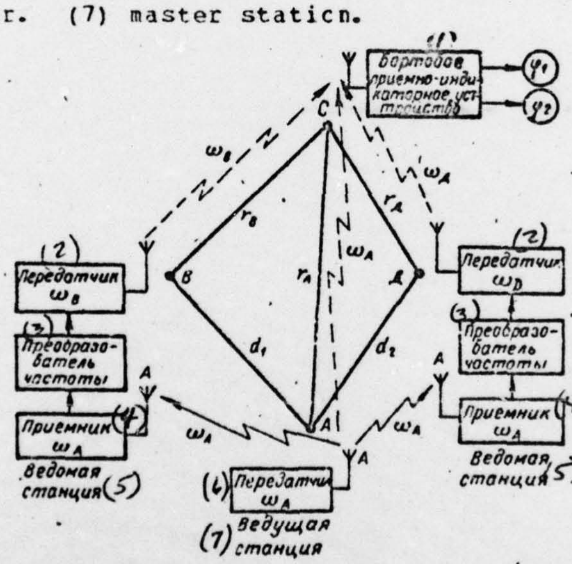
$$\begin{gathered} n\omega_A = m\omega_B = \omega_{C1}; \\ m\omega_A = l\omega_Д = \omega_{C2}. \end{gathered} \tag{3.31}$$

The pair of the stations AV, arrange/located on base d_1, during joint operation forms the family (grid) of lines of position whose number is determined by relation $\frac{d}{\lambda_{C1}}$ where $\lambda_{C1} = \frac{2\pi c}{\omega_{C1}}$.

Page 133.

Fig. 3.8. Diagram cf phase differential ranging system.

Key: (1) on-board receiving-indicator device. (2) transmitter. (3) frequency converter. (4) receiver. (5) slave station. (6) transmitter. (7) master station.



The pair of the stations of $\overset{[AB]}{\underset{1}{AD's}}$. arrarge/located on base d_2. in joint operation they give their family of lines of position depending on relation $\frac{d_2}{\lambda_{c2}}$ where $\lambda_{c2}=\frac{2\pi c}{\omega_{c2}}$.

On aircraft with the aid of reception indicator device are measured phase differences:

$$\varphi_1=\frac{2\pi}{\lambda_{C1}}(r_B-r_A); \quad \varphi_2=\frac{2\pi}{\lambda_{C2}}(r_{\text{Д}}-r_A). \qquad (3.32).$$

From the obtained values of phase differences are determined the lines of position from the first and second semsystva LP_1 and LP_2, while from them the position of aircraft. It is necessary in this case to emphasize that the families lincy position on the first and second bases are assigned to scale of standard frequencies ω_{c1} and ω_{c2} although actually the emission/radiation and the reception of signals in system it is realized at frequencies ω_A, ω_B and $\omega_{\text{Д}}$.

Page 134.

Let us examine the method of the synchronization of work of ground stations on an example of the joint operation of master station A and to slave station $\cancel{X}$ B. Block diagram of slave station to privedene in Fig. 3.9. The fluctuations of master station at frequency ω_A are

received as antenna A_1, they are amplified and enter two channels: the channel of the formation of the emitted fluctuations, which serves for the agreement of frequencies ω_A and ω_B and the channel of the tuning of phase, intended for the agreement of the phases of the fluctuations, emitted as the leading and slave stations.

In the channel of formation the frequency ω_A is divided into m, then it is multiplied twice by $\sqrt{n}$ and is supplied to the transmitter of slave station, which emits its fluctuations into space through the antenna A_2 at frequency $\omega_B = \frac{n}{m}\omega_A$.

These fluctuations are received as antenna A_3, are amplified and enter channel the tunings of the phase where the frequency ω_B is multiplied by m and approaches phase discriminator. There are supplied to the fluctuations, accepted from the master station, pre-multiplied by n. As a result for the inlet of phase discriminator enter two signal with identical standard frequency ω_{C1}; in phase discriminator is conducted the comparison of phases and is developed the error signal, which through the control affects the phase of the fluctuations of the transmitter of slave station until the error signal becomes equal to zero. Besides the automatic tuning of the phase of slave station, is provided also its manual tuning and control with the aid of reference monitor. ¶ The block diagram of installed equipment is given in Fig. 3.10. The signals of all three ground stations are accepted to one antenna and are divided into three channels. After amplification these signals are supplied to frequency multipliers. After the frequency multiplication of the pair ~~AV~~ AB by n and m are obtained two fluctuations at standard frequency ω_{C1} while

after the frequency multiplication of the pair of AD's by m and l are form/shaped two fluctuations on standard frequency ω_{c2} (3.31). These pairs of fluctuations are supplied to two phase-measuring devices, the obtained designation decometers, intended for the measurement of a phase difference ϕ_1 and ϕ_2. The results of measurements are represented on the appropriate dial instruments. The accuracy of the measurement of a phase difference with the aid of decometers is characterized by root-mean-square error σ_ϕ the order of 1/100 phase cycles.

In system "sounding board", for example, can be utilized the following set of frequencies:

$$f_A = 85 \text{ kHz}; \quad f_B = 113\tfrac{1}{3} \text{ kHz}; \quad f_D = 127\tfrac{1}{2} \text{ kHz}.$$

Fig. 3.9. Block diagram of slave station with frequency channel separation.

Key: (1) the channel of the formation of the emitted fluctuations. (2) manual phase control. (3) amplifier. (4) frequency divider to m. (5) frequency multiplier ~~on~~ to $\sqrt{n}$ (6) frequency multiplier ~~on~~ to $\sqrt{n}$. (7) driven transmitter $\omega_B = \frac{n}{m}\omega_A$. (8) the equalizer of phase. (9) the channel of the tuning of phase. (10) frequency multiplier to n. (11) phase discriminator. (12) frequency multiplier to m. (13) amplifier ω_B. (14) reference monitor.

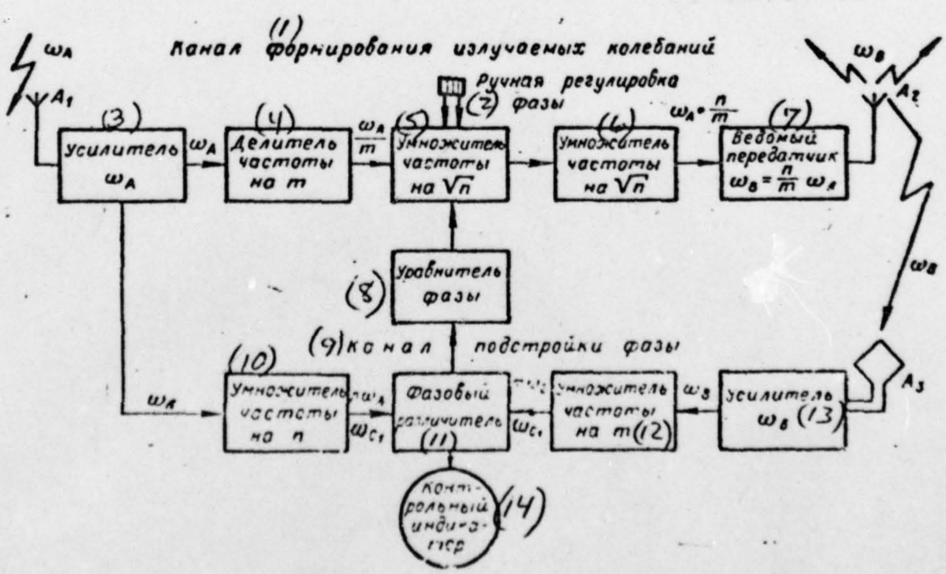
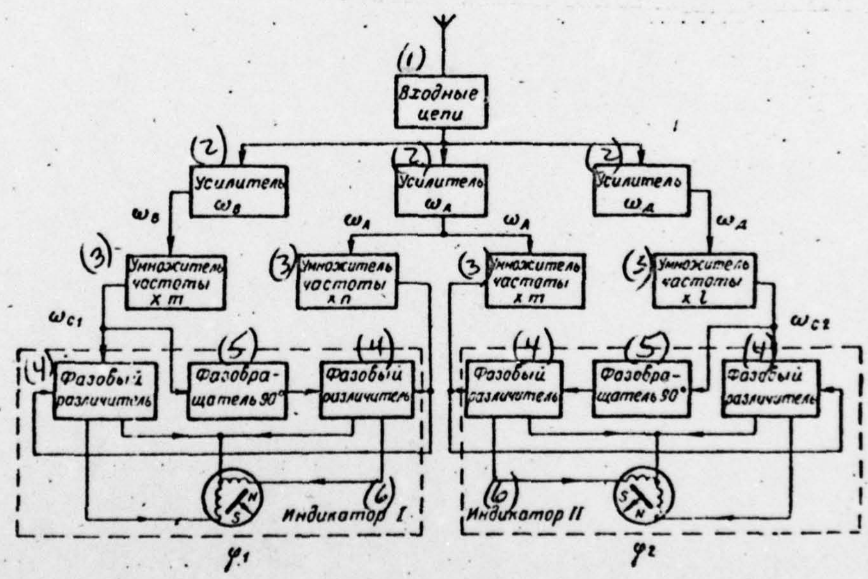


Fig. 3.10. Block diagram of the on-board reception indicator device of phase system with frequency channel separation.

Key: (1) output circuits. (2) amplifier. (3) frequency multiplier. (4) phase discriminator. (5) phase inverter 90°. (6) indicator.



Page 137.

For obtaining the first standard frequency the frequency of the leading signal is multiplied by n = 4, and the frequency of driven - to m = 3, as a result

$$f_{c1} = 4 \cdot 85 = 3 \cdot 113\frac{1}{3} = 340 \text{ kHz}.$$

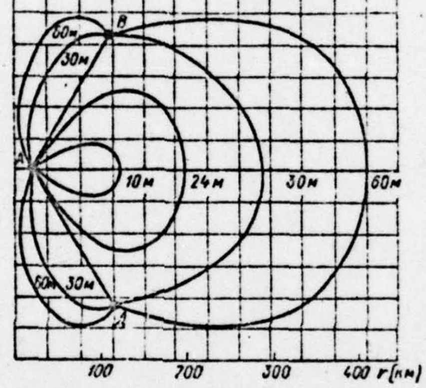
For obtaining the second standard frequency the frequency of the leading signal is multiplied by m = 3, and the frequency of the second driven - on l = 2 is obtained

$$f_{c2} = 3 \cdot 85 = 2 \cdot 127\frac{1}{2} = 255 \text{ kHz}.$$

The operating region of system of three stations [ABA] AVD is oriented predominantly in one direction (Fig. 3.11). For the target/purpose of the provision for circular maintenance into system can be introduced one additional slave station E with carrier frequency $f_E = 70\frac{5}{6}$ kHz. Then the pair of stations AE forms one additional base d_3 with standard frequency

$$f_{c3} = 5 \cdot 85 = 6 \cdot 70\frac{5}{6} = 425 \text{ kHz}.$$

Fig. 3.11. The operating region of phase differential ranging system.



Page 138.

For obtaining navigational information from this system into installed equipment is introduced the fourth channel and the third phase-meter device. Location that which drive and three slave stations in locality is shown in Fig. 3.12.

Ambiguity in reading is removed with the aid of the coarse grid of lines of position, which is created by the following method. Each station periodically emits signals simultaneously at two frequencies, which differ by 14 1/6 kHz, the value, which is the greatest common divisor of frequencies of all four stations.

As a result of reception on the aircraft simultaneously of two signals at different frequencies from each ground station are formed the beatings, that makes it possible to isolate difference frequency $f_{rp} = 14\frac{1}{6}$ kHz and to utilize it as standard frequency for the formation of coarse grid on base will be

(3.33). $$\chi_{0_{rp}} = \frac{\lambda_{rp}}{2} = \frac{c}{2f_{rp}}$$

At standard frequency $f_{rp} = 14\frac{1}{6}$ kHz

$$\chi_{0_{rp}} = \frac{3\cdot 10^8}{2\cdot 14\frac{1}{6}} = 10,500 \ m.$$

For the elimination of ambiguity the master station A emits frequencies 85 kHz and 70 5/6 kHz, driven B - frequency 113 1/3 kHz even 127 1/2 kHz, driven R - frequency 127 1/2 kHz even 113 1/3 kHz, driven E - frequency also 113 1/3 kHz even 127 1/2 kHz. These pairs of frequencies are emitted by leading and one of the slave stations during 5 s by three cycles with the 1st, 16th and 31 s of each minute, but two other driven to this time are disconnect/turned off. During the 1st cycle works vapor [AB] and is formed the coarse grid on base d_1 during the 2nd cycle - the pair of [AR]'s and it is form/shaped coarse grid on base d_2 and finally during the 3rd cycle it works vapor AE and it is created coarse grid on base d_3.

Fig. 3.12. Location of the ground stations of phase system.

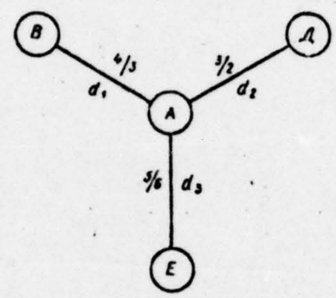
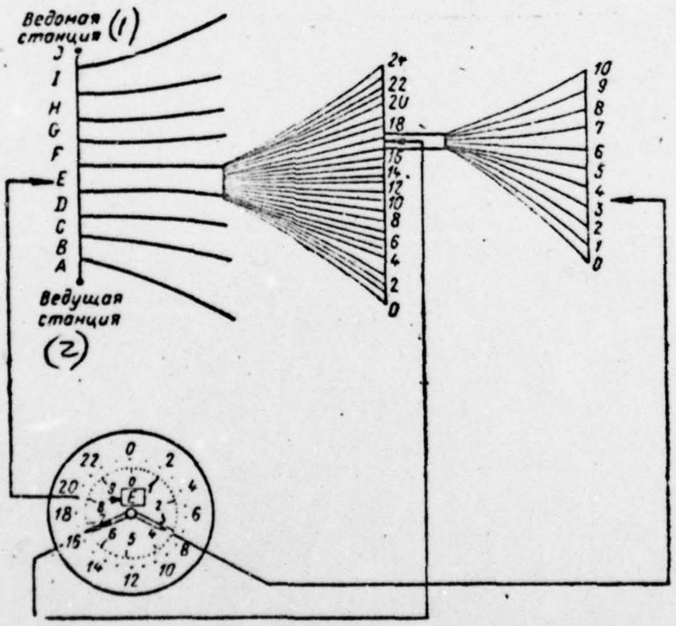


Fig. 3.13. Diagram of obtaining unequivocal reading in phase system.

Key: (1) slave station. (2) master station.



In those which were remaining 45 s of each minute all 4 stations of group work simultaneously, creating precise phase grids. The necessary mode switches of work are conducted in the special fast signals of master station, sent before each cycle at the frequency, which differs from carrier 85 kHz on 70 Hz.

For a use by such systems are released the special map/charts on which are plotted/applied the zones of coarse grid, path/track of a precise grid and line of position. Zones are designated by the letters of Latin alphabet, their number on each base equal to the relation:

$$\frac{d}{\chi_{0_{rp}}} = \frac{2d}{\lambda_{rp}}$$

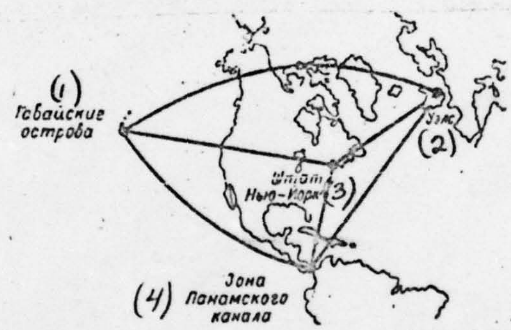
The number of path/tracks in each zone, in turn, is equal to the relation of standard frequencies:

$$\frac{f_c}{f_{rp}} = \frac{\chi_{0_{rp}}}{\chi_0} = \frac{\lambda_{rp}}{\lambda} \quad (3.34).$$

Page 140.

Fig. 3.14. Arrangement/permutation of the ground stations of phase system "omega".

Key: (1) Hawaiian islands. (2) Wales. (3) the state of New-York. (4) the zone of Panama Canal.



The number of lines of position in each path/track is selected equal to 10C (through 3.6°), and is figured of them each the tenth. Respectively each decometer have three of scales: the scale of zones in the form cf letters in the window cf dial, the scale of path/tracks and the scale of lines of position with the appropriate needle indicators. Figure 3.13 shows a diagram of numbering and an example of the reading of line of position E-16-30. The plotted/applied by map/chart lines of position of different bases differ in terms of color and the appropriated to the path/tracks of a precise grid numbers.

Let us examine one additional developed in the USA phase differential ranging system "omega" which is introduced at present into field testing. The location of the ground stations of this system is shown in Fig. 3.14. One of the stations on Hawaiian islands, is driving, and the others - by driven. In all it is assumed to be to establish/install 8 stations, which work on very long waves, and to create the continuous navigational field above an entire surface of terrestial globe.

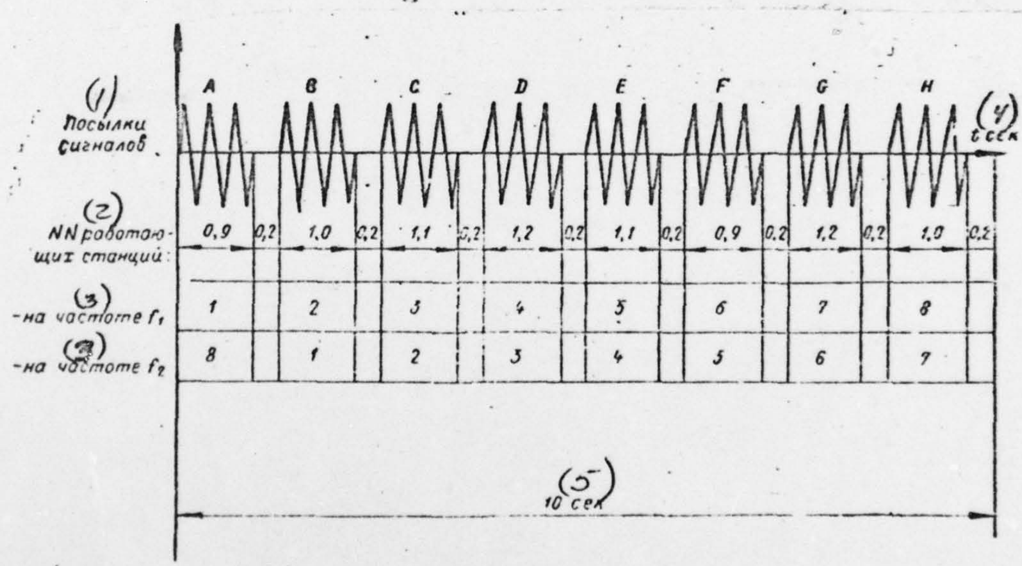
The ground stations of system "omega" work in turn on two frequencies f_1 = 10.2 kHz and f_2 = 13.6 kHz, emitting the unmodulated fluctuations at each carrier frequency during ~1 s with repetition period 10 s. From the operating schedule of operation eight of ground stations (Fig. 3.15) it is evident that the stations of system must work on transmission consecutively and it is strict in concord on time at intervals 0.2 s so that during the complete cycle of transmission

each station would make two send operations of the signals: one at frequency f_1, another at frequency f_2. In the first time interval during 0.9 s, works on transmission station 1 at frequency f_1 and station 8 at frequency f_2 (send operation A).

Page 141.

Fig. 3.15. The operating cycle of the transmission of signals by ground stations.

Key: (1) the send operations of signals. (2) NN the working stations. (3) at frequency. (4) t s. (5) s.



Page 142.

Then after pause 0.2 s work station 2 at frequency f_1 and station 1 at frequency f_2 (send operation B). Further enters the work station 3 and emits its signal at frequency f_1, but preceding/previous station 2 at this time emits fluctuations at frequency f_2 etc. before completion of the complete cycle of transmission, whereupon begins new cycle. For the realization of this curve/graph each stanitsya contains special electron commutator (timer), which realizes the necessary mode switches of work of all units of station.

The emission/radiation of ground stations at frequency f_1 is utilized for compiling a precise phase grid of lines of position, while emission/radiation at frequency f_2 is utilized for the elimination of multiformity in reading.

Matched work of each pair of the ground stations, arrange/located at the end/leads of base d, on the first frequency makes it possible to create a precise phase grid of lines of position whose number, according to formula (3.13) will be

$$N = \frac{720}{\sigma^{\circ}_{\varphi}} = \frac{d}{\lambda_1} \tag{3.35}$$

where $\lambda_1 = c/f_1$.

Width of the phase path/track of a precise grid on the base

(3.36). $$\chi_0 = \frac{\lambda_1}{2} = \frac{c}{2f_1}$$

At the selected frequency f_1 = 10.2 kHz x_0 will be about 15,000 m. Matched work of these stations on the second frequency f_2 makes it possible to isolate the difference

(3.37) $$f_{rp} = f_2 - f_1$$

and to obtain the rough phase grid of lines of position with the width of zone on the base

(3.38). $$\chi_{o_{rp}} = \frac{\lambda_{rp}}{2} = \frac{c}{2f_{rp}} = \frac{c}{2(f_2 - f_1)}$$

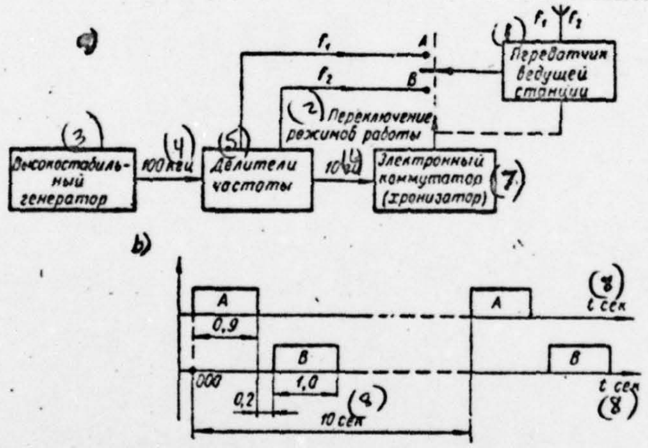
At the selected frequency f_2 = 13.6 kHz χ_0 will be

$$\chi_{o_{rp}} = \frac{3 \cdot 10^8}{2(13.6 - 10.2)10^3} \approx 45,000 \ m.$$

i.e. in each zone of coarse grid are located three path/tracks of a precise grid. Subsequently is assumed to be to conduct work on one more frequency f_3 = 12.75 kHz, which makes it possible to expand the zone of unequivocal reading.

Fig. 3.16. Block diagram of master station and the schedule of its operation.

Key: (1) the transmitter of master station. (2) the mode switch of work. (3) high-stability oscillator. (4) kHz. (5) frequency dividers. (6) Hz. (7) electron commutator (timer). (8) s.



Let us examine the joint operation of the pair of ground-based stanitsy, consisting of master station 1 and slave station 3. The block diagram of master station is given in Fig. 3.16a. The diagram contains the high-stability oscillator of frequency 100 kHz, relative frequency drift of which it composes 10^{-8}-10^{-9} for days. The fluctuations of oscillator are supplied to the unit of frequency dividers, at output/yield of which are obtained two frequencies f_1 and f_2 for the excitation of transmitter even one - 10 Hz for a control of work of electron commutator. The latter during 10 s the cycle of commutation develops two send operations (Fig. 3.16b), work superintendent of the transmitter of the master station:

- send operation A, during which the transmitter emits fluctuations at frequency f_1;

- send operation B, during which the transmitter emits fluctuations at frequency f_2.

The frequency of high-stability oscillator is compared with the frequency of pattern generator and periodically is corrected. The electron commutator, controlled 10 Hz by signal, is regulated so that send operation A would begin accurately in zero second after midnight on Greenwich time, then emitted by the leading transmitter of fluctuation can serve as the strictly standardized signals of precise time in the service of single time.

Page 144.

With relative frequency stability 10^{-8} shift in the operating time of electron commutator will compose value

$$\Delta t = 10^{-8} T \tag{3.39}$$

that for days it will give less than 10^{-3} s (one second for 3 years).

Slave station must emit into space its signals, strictly in concord with the signals of master station on frequency and the initial phase. Only under this condition it is possible on the basis of the measurement of a phase difference to obtain the line of position. Furthermore, the signals of driven transmitter must be emitted into the strictly assigned intervals of time, according to the curve/graph of Fig. 3.15. In our case at slave station 3 for the emission/radiation of signals within limits 10 s of operating cycle are abstract/removed the time intervals C and D. For this purpose the slave station is placed in the mode/conditions of tracking the signals of master station, which can be examined with the aid of the block diagram, presented in Fig. 3.17.

Page 316

05-15-76

Fig. 3.17. Plock diagram cf slave station with tiem-division multiplexing.

Key: (1) master station. (2) slave staticn. (3) receiver. (4) amplifier. (5) mcde switch. (6) transmitter. (7) channel. (8) master staticr. (9) slave station. (10) control. (11) synchronizer. (12) electrcn ccmmutator. (13) frequency dividers. (14) Hz. (15) kHz. (16) high-stability oscillatcr. (17) the send operaticns of master staticr. (18) the send operations cf slave station. (19) switching the razhimov cf work.

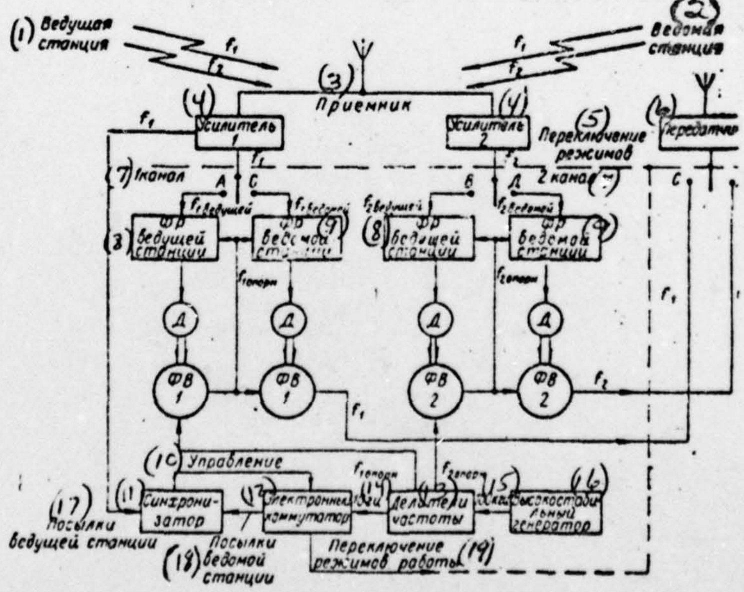
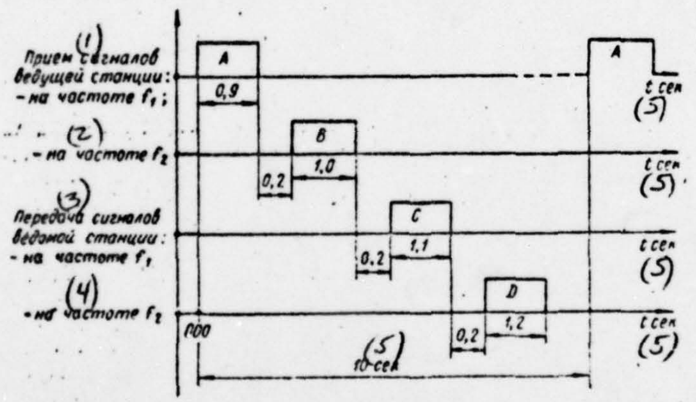


Fig. 3.18. Curve/graph of work of the channels of slave station.

Key: (1) the reception of the signals of the master station: - at frequency f_1. (2) at frequency f_2. (3) the transmission of the signals of slave station - in frequency f_1. (4) at frequency f_2. (5) s.



Slave station accepts the send operations of the signals of master station A and B consecutively at frequencies f_1 and f_2 with the aid of diplex receptor. At station there is their high-stability oscillator, which operates at a frequency of 100 kHz and a frequency divider, which develops continuous fluctuations at frequencies f_1 and f_2, intended for the excitation of driven transmitter. In addition to this, the divider/derominator develops another fluctuations at frequency 10 Hz (duration of period 0.1 s), which control work of electron commutator, and the latter in turn, must manufacture 4 send operations of signals in each operating cycle:

- send operation A and B for the consecutive reception of signals from master station at frequencies f_1 and f_2;

- send operation C and D for the successive emission of the fluctuations of slave station also at frequencies f_1 and f_2.

Moreover these both fluctuations must be sent to the strictly defined time intervals in accordance with the time diagram of Fig. 3.18.

For the agreement (synchronization) of work of the commutator of slave station with work of commutator that which drive is a synchronizing unit in which is conducted the comparison of the send operations of master station with the send operations of slave station, manufactured by its commutator, and is realized the adjustment of commutator. After the achievement of synchronism in work the commutator of slave station automatically produces all the necessary mode switches at the established/installed points in time.

Page 146.

The send operations of signals A from master station at frequency f_1 are received as the first channel of receiver and after amplification are supplied to phase discriminator ~~PR~~ ФР$_1$ master station, where enter also the continuous fluctuations at frequency f_1, manufactured by frequency divider from fluctuation at frequency f_1, manufactured by frequency divider from the fluctuations of the local oscillator. The error voltage of disagreement/mismatch with respect to phase from the output/yield of phase discriminator is supplied to engine Д and controls the rotation/revolution of phase inverter ~~PV~~ ФВ the master station of the first channel. This phase inverter shift/shears the phase of the fluctuations of reference voltage $f_{1\,опорн}$ until these fluctuations turn out to be out of phase relative to received signal $f_{1\,вед}$ accurately by 90° and the error signal in this case will become equal to zero.

The matched on phase with received signal supporting/reference fluctuations $f_{1\,опорн}$ are supplied to phase discriminator ~~PR~~ ФР and phase inverter ~~PV~~ ФВ$_1$ the slave station of the first channel.

Analogous process is observed when using send operations B from master station at frequency f_2 in the second channel of the receiver, as a result of which the matched on phase with received signal supporting/reference fluctuations $f_{2\,опорн}$ are supplied to phase discriminator ~~PR~~ ФР$_1$ and phase inverter ~~PV~~ ФВ$_1$ the slave station of second channel.

During time interval C supporting/reference fluctuations at frequency f_1 are supplied to the driven transmitter which emits signal at frequency f_1 into space. These fluctuations are received as the antenna of receiver, enter the first channel and is supplied to phase discriminator ФР$_1$ slave station. After their comparison with supporting/reference at the output/yield of phase discriminator is separate/liberated the error signal of disagreement/mismatch on the basis of the phase between the emitted and supporting/reference fluctuations of slave station at frequency f_1.

This signal controls work of engine Д and rotation of phase inverter ФВ$_1$ the slave station of the first channel until mismatch error is brought to zero. In this case the emitted signal vecdmoy station turns out to be out of phase relatively supporting/reference by 90°. Since the taken signal by that driving the obtained signal of driver out of phase relative to common/general/total supporting/reference fluctuation by identical angle of 90°, they will coincide in the phase between themselves.

Analogous process occurs during time interval Д, when supporting/reference fluctuations at frequency f_2 are supplied to vecdmyy transmitter. Emitted to them fluctuations at frequency f_2 approach phase discriminator ФР$_1$ the slave station of second channel and with the aid of phase inverter ФВ$_1$ the slave station of this channel are matched on phase with received signal at frequency f_2.

Page 147.

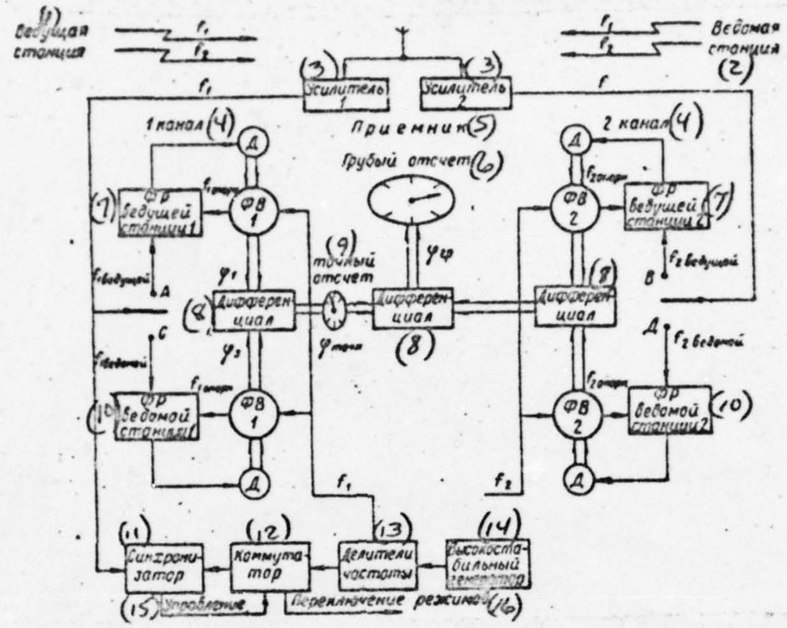


Fig. 3.19. The block diagram of the on-board reception indicator device of phase system with time-division multiplexing (voltage of frequency f_2 is supplied to phase inverters from frequency dividers analogous with Fig. 3.17).

Key: (1) master station. (2) slave station. (3) amplifier. (4) channel. (5) receiver. (6) coarse reading. (7) master station. (8) differential. (9) fine reading. (10) slave station. (11) synchronizer. (12) commutator. (13) frequency dividers. (14) high-stability oscillator. (15) control. (16) mode switch.

Since by the examined method are zastabilizirovany the phases of the fluctuations of slave station at frequencies f_1 and f_2 relative to signals driving, the phase of difference frequency $f_2 - f_1$ also will be stable relative to the phase of difference frequency driving.

Also processes flow/last in the units of another slave stations, differing only in time of the send operations of their signals.

The block diagram of the on-board receiving-measuring device of Fig. 3.19 contains two channel for the reception of signals from the leading and slave stations at frequencies f_1 and f_2 from each and the measurement of a phase difference. The electron commutator, synchronized as the signals of master station, serves for the mode switch of work of receiving-measuring device according to the determined program into the strictly assigned points in time analogous with work the commutator of slave station.

Page 148.

For example for the reception of signals from the master station of 1 and slave station 3 commutator after synchronization will switch in the diagram of priyemoindikatora according to the program of Fig. 3.18. In this case the send operations A from master station at frequency f_1 will approach phase discriminator ΦP_1 the master station of the first channel, and send operation B at frequency f_2 - at ΦP_1 the master station of second channel. In turn, send operations C and $\cancel{D}$ of slave station will be accepted and given on the phase discriminators

of the slave station of the first and second channels. Thus the channel of time selection, utilizing successive work of ground stations, distributes the taken from them signals by the appropriate channels of on-board receiving-measuring device.

Into the measuring circuit of the first channel from the unit of divider/denominators comes the reference voltage of the first operating frequency. Continuous fluctuations $f_{1\ опорн}$ through phase inverters are supplied on the phase discriminators where they are compared with respect to phase with the taken signals from ground stations. The error signals cause the rotation of the rotors of phase inverters through this angle by which the phase of reference voltage differs from the phase of the taken signals accurately by 90°. The angles of rotation of the axes of the phase inverters of the leading and slave stations transmit to the mechanical differential, output axis of which is turned to the angle, which characterizes a phase difference of the taken signals by frequency f_1. With axis is connected the rifleman/gunner of fine reading.

The same processes flow/last in the second channel of the measuring circuit where is determined the phase difference of the taken signals from ground stations at frequency f_2. This phase difference is expressed by the angle of rotation of the output axis of the corresponding differential.

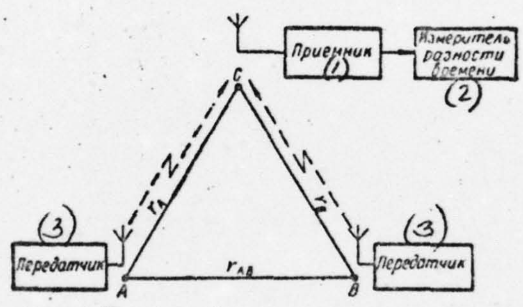
Now it turns out to be possible to utilize results of measurements in the first and second channels for obtaining coarse reading for the target/purpose of the partial elimination of ambiguity. For this purpose output differential shafts 1 and 2

channels are supplied to the third differential which makes it possible to determine the difference between their angular positions, and this difference it gives to us reading on coarse grid with the width of zone on base according to formula (3.38).

Page 149.

Fig. 3.20. Operating principle of time/temporary differential ranging system.

Key: (1) receiver. (2) the meter of a time difference. (3) transmitter.



Actually, a phase difference from 1 and 3 stations at frequency f_1 it will compose the value:

$$\varphi_1 = 2\pi \frac{f_1}{c}(r_3 - r_1)$$

a at frequency f_2

$$\varphi_2 = 2\pi \frac{f_2}{c}(r_3 - r_1)$$

A difference in these values will give

$$\varphi_{rp} = \varphi_2 - \varphi_1 = 2\pi \frac{f_2 - f_1}{c}(r_3 - r_1)$$

Accepting on base $r_3 - r_1 = 2x_{0\,rp}$, $\varphi_{rp} = 2\pi$ we will obtain

$$x_{0_{rp}} = \frac{c}{2(f_2 - f_1)}$$

§ 3.4. Operating principles of time/temporary delivered-ranging systems.

[redacted]

[redacted]

Page 149 continued.

For the creation of time/temporary type differential ranging system are required two ground stations which are establish/installed at a great distance from each other r_{AB} (Fig. 3.20), called base. The transmitters of these stations operate on a pulsed basis of emission/radiation, strictly matched on time at identical carrier frequency.

For the agreement one of the ground stations A fulfills functions driving, and another B - slave station. Master station assigns the common/general/total operating mode of an entire system, the repetition frequency of transmitted pulses, and driven follows its work and emits its pulse signals with the strictly assigned time delay.

Page 150.

Aboard the aircraft is establish/installed the receiver and measuring device, with the aid of which are accepted the signals of both ground stations and is conducted the measurement of a time difference of their reception on aircraft.

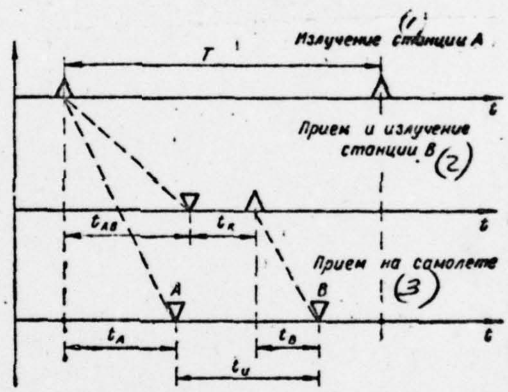
From this time difference is determined the difference in the distances from ground stations to aircraft, and then is located the line of position - the line of equal differences in the distances LRRB.

With this method of operation as in phase systems, on aircraft it is not required to establish/install the transmitters whose power is always strongly limited. Emission/radiation is realized only by ground stations whose power can be the sufficiently large in order to ensure the long range of action. On aircraft is conducted the only method of this emission/radiation; therefore the number of aircraft, which simultaneously obtain information, virtually not limitedly; consequently, differential ranging systems can have the unlimited capacity.

The processes of emission/radiation and reception of pulse signals in time/temporary type differential ranging system are shown in Fig. 3.21. On the upper row of time diagram it is shown that leading stantsiya emits into space pulse signals (depicted conditionally in the form of triangles) with repetition period T which is selected by the sufficiently large in order that up to the torque/moment of the send operation of the following signal on aircraft would end the reception of the previous signals, sent by stations A and B. In the systems of long-range the frequency of send operations F =1/T is selected equal to several dozen momentum/impulse/pulses per second, which provides obtaining unequivocal reading independent of range.

Fig. 3.21. The time diagram of emission/radiation and reception of pulse signals.

Key: (1) the emission/radiation of station A. (2) the reception and the emission/radiation of station B. (3) reception on aircraft.



Page 151.

Emitted as station A signals are received at station B and on aircraft. The reception of signals at station B occurs with time lag for a period t_{AB} proportional to the length of base r_{AB} :

$$t_{AB} = \frac{r_{AB}}{c} \quad (3.40).$$

Processes in the circuits of station B are given on the second row of diagram. After reception the signals are delayed for some time t_k which it is composed of the transit time of momentum/impulse/pulses along the different circuits of ground station (antenna, receiver, shapers, transmitter) and of delay time in special line. The value of code delay t_K can be selected different and in the process of work is supported by strictly constant. After this time station B emits into space its pulse signal which also is accepted on aircraft.

On the third row of diagram it is shown that the aircraft receiver in each cycle of work of system obtains two signal:

- momentum/impulse/pulse from station A with time lag t_A after its emission/radiation by station A;

- momentum/impulse/pulse from station B with time lag t_B after its emission/radiation by station B.

In this case the time lag t_A and t_B with respect to the torque/moments of their emission/radiation at stations A and B will be

proportional to distances r_A and r_B :

(3.41). $$t_A = \frac{r_A}{c}; \quad t_B = \frac{r_B}{c}$$

According to time diagram a time difference the reception of these signals on aircraft will compose the value:

(3.42). $$t_n = t_{AB} + t_K + t_B - t_A.$$

Delay factors t_{AB} and t_K in the process of work are retained constants. Let us designate this constant t_0:

(3.43). $$t_0 = t_{AB} + t_K$$

Then we obtain

(3.44). $$t_n - t_0 = t_B - t_A$$

Page 152.

By substituting here values t_A and t_B from (3.41), we will obtain:

(3.45). $$t_{\text{H}} - t_0 = \frac{1}{c}(r_B - r_A).$$

Whence

(3.46). $$r_B - r_A = c(t_{\text{H}} - t_0).$$

The obtained formula connects a time difference the reception of signals on aircraft t_{H} from the ground stations A and B with a difference in the distances of aircraft of these stations r_A and r_B. If we in the process of flight retain the measured value t_{H} constant, then in this case will be retained constant a difference in the distances: $t_{\text{H}} = const$, $r_B - r_A = const$. Consequently, to each value t_{H} will correspond the line of position in the form of equal differences in the distances.

Let us examine, as will change the value of a time difference t_{H} in moving aircraft in space relative to the pair of the ground stations, arrange/located at the end/leads of the base r_{AB}. We will use formula (3.42) and let us determine value t_{H} for three characteristic points (Fig. 3.22). At point 1, arrange/located to the left during the continuation of base (from the side of master station):

(3.47). $$t_{B1} - t_{A1} = t_{AB}$$
$$t_{\text{H}1} = 2t_{AB} + t_K'$$

At point 2, arrange/located on the perpendicular, restored/reduced from the middle of the base:

$$t_{B2} - t_{A2} = 0$$
$$t_{M2} = t_{AB} + t_K \quad (3.48).$$

At point 3, arrange/located to the right during the continuation of base (from the side of slave station):

$$t_{B3} - t_{A3} = -t_{AB};$$
$$t_{M3} = t_K. \quad (3.49).$$

As can be seen from the comparison of the obtained results, with the method of operation in question a time difference the reception of signals on aircraft from the ground stations A and B during its shift changes unambiguously. Hence it may be concluded that the results of the determination of lines of position in this system will be also unequivocal.

Fig. 3.22. Change in the time difference the reception of signals in moving aircraft.

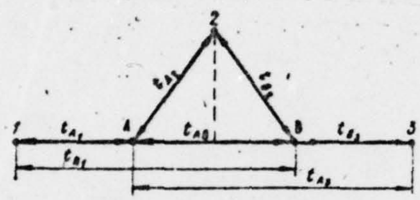
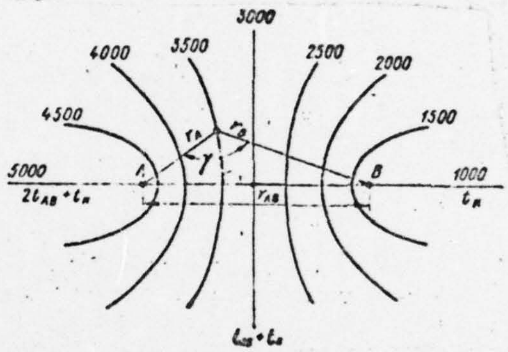


Fig. 3.23. Family of the lines of position of time/temporary differential ranging system.



This large advantage of time/temporary systems in comparison with phase systems.

In moving aircraft over any arbitrary trajectory from point 3 into point 1 measured time difference $t_{н}$ will smoothly change from the minimum value $t_{н\ мин} = t_{K}$ to the maximum $t_{н\ макс} = 2t_{AB} + t_{K}$ i.e. within the limits

$$t_{н\ макс} - t_{н\ мин} = 2t_{AB}. \qquad (3.50)$$

If the mean square error of the measurement of time is characterized by value σ_t that in the system in question it is possible to obtain family from N of lines of position where

$$N = \frac{t_{н\ макс} - t_{н\ мин}}{\sigma_t},$$

a taking into account (3.50)

$$N = \frac{2t_{AB}}{\sigma_t}. \qquad (3.51)$$

If, for example, base is selected by length $r_{AB} = 600$ km, and the accuracy of the measurement of time $\sigma_t = 2\ \mu s$, then

$$t_{AB}=\frac{r_{AB}}{c}=\frac{600\cdot10^3}{3\cdot10^8}=2\cdot10^{-3}\ s;$$
$$N=\frac{2\cdot2\cdot10^{-3}}{2\cdot10^{-6}}=2000,$$

and each of them will be determined unambiguously.

Figure 3.23 depicts the family of the lines of position, distant from each other on 500 µs with code delay t_K = 1000 µs. With a change in the value of code delay it is possible to change the numbering of lines of position.

Page 154.

To evaluate the accuracy of time/temporary differential ranging systems let us differentiate formula (3.46) and pass to the finite increments. Then we obtain:

(3.52). $$\Delta r = c\Delta t_H,$$

Expression (3.52) connects the measuring error of a time difference Δt_H with the measuring error of a difference in the distances Δr. This communication/connection will occur also between the root mean square values of these errors:

(3.53). $\sigma_r = c\sigma_t$

In turn, the error in the measurement of a difference in the distances will cause the error in the determination of line of position. According to (3.16) the linear line shift of position will be:

$$\sigma = \frac{\sigma_r}{2\sin\frac{\gamma}{2}}$$

a taking into account (3.53)

$$\sigma_* = \frac{c\sigma_t}{2\sin\frac{\gamma}{2}}, \quad (3.54)$$

where γ is an angle of base. In the position of aircraft on base this angle is equal to 180°, and the line shift of the position

$$\sigma = \frac{\sigma_r}{2} \quad (3.55)$$

or

$$\sigma = \frac{c\sigma_t}{2}$$

If $\sigma_t = 2\mu s$, then

$$\sigma = \frac{3\cdot 10^8 \cdot 2\cdot 10^{-6}}{2} = 300\ m.$$

According to formula (3.19) at large distances from base a difference in the distances is expressed by the dependence:

(3.56). $$r_B - r_A = r_{AB}\sin\alpha.$$

By substituting it in (3.46), we will obtain $r_{AB}\sin\alpha = c(t_н - t_0)$.

Page 155.

By differentiating both parts of this expression, let us find $r_{AB}\cos\alpha d\alpha = cdt_н$.

Whence

$$d\alpha = \frac{cdt_н}{r_{AB}\cos\alpha}$$

or in the finite increments

(3.57). $$\Delta\alpha = \frac{c\Delta t_н}{r_{AB}\cos\alpha}.$$

The last/latter expression shows the communication/connection between

the measuring error of time Δt_{u} and the angular displacement of line of position $\Delta\alpha$. Analogous communication/connection also between the mean square errors:

$$\sigma_{\alpha} = \frac{c\sigma_{t}}{r_{AB}\cos\alpha}. \tag{3.58}$$

minimum value of which it will be on the perpendicular, restored/reduced from the middle of base. When $\alpha = 0$

$$\sigma_{0} = \frac{c\sigma_{t}}{r_{AB}} \tag{3.59}$$

or

$$\sigma_{0} = \frac{\sigma_{t}}{t_{AB}}.$$

For determining place in time/temporary systems are also necessary two bases with the intersecting lines of position (Fig. 3.7). The radial errors in determination of place are calculated from formulas (3.27) and (3.28).

[ΦA30]

§ 3.5. Operating principles of FAZO-time/temporary differential ranging systems.

The comparison of time/temporary differential ranging systems with phase shows that incorporating advantages in obtaining unequivocal reading, they considerably are inferior to phase systems in the relation to the accuracy of measurements. In order to be equalized with phase systems on accuracy, time/temporary systems must have on-board measuring devices with accuracy $\sigma_t = 0.1-0.01 \mu s$. This served as the reason for creation and rapid development of fazo-time/temporary type combined systems, which successfully combine in themselves positive the quality of each, i.e., they possess high accuracy and uniqueness in reading.

In fazo-time/temporary systems the elimination of ambiguity in reading is achieved by the measurement of time, and an increase in the accuracy - by the measurement of a phase difference.

Page 156.

For the realization of [ФА 30] fazo-time/temporary principle ground stations work in the mode of coherent pulse emission/radiation (Fig. 3.24). The transmitted pulses are cuts from continuous high-frequency oscillation with repetition period, multiple to the period of high-frequency oscillations:

$$T = n \frac{1}{f},$$

where f they is carrier frequency, and n is the integer.

During this operating mode the phase of high-frequency filling turns out to be strictly connected with that which go around pulse signal, which makes it possible to use aboard the principle of the coherent reception of the oscillations, emitted by ground stations.

Work of the leading and slave stations in these systems is matched on time of emission/radiation in the manner that this is made in time/temporary systems (see Fig. 3.21), and also on phase, as this is necessary in phase systems. The signals of the leading and slave stations are received aboard as the receiving-measuring device where is conducted the measurement of a time difference of the arrival of the pulse signals:

$$t_{\text{и}} = t_{AB} + t_{\text{з}} + (t_B - t_A),$$
$$t_B - t_A = \frac{1}{c}(r_B - r_A)$$

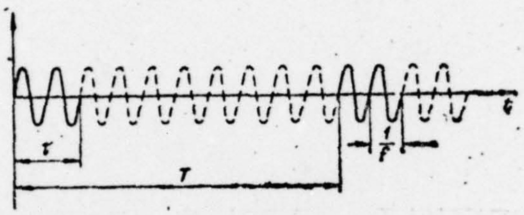
and the measurement of a phase difference of the high-frequency oscillations, which fill these pulse signals:

$$\varphi_B - \varphi_A = \frac{2\pi}{\lambda}(r_B - r_A).$$

As a result of the measurement of a time difference is determined the difference in the distances with this accuracy in order to unambiguously find that phase path/track, in limits of which is located the aircraft. As a result of the measurement of a phase

difference accurately is determined the line of position within this path/track.

Fig. 3.24. Coherent pulse emission/radiation of ground station.



Page 157.

Requirements for the accuracy of measurements are reduced in order that the middle quadratic oshbika of the measurement of time would be not more the fourth of the period of high-frequency oscillation:

(3.60). $\sigma_t \leq \frac{1}{4}\frac{1}{f}$.

Multiplying both parts of this expression to the velocity of radiowave propagation, we obtain:

$$c\sigma_t \leq \frac{1}{4}\frac{c}{f}$$

or

(3.61). $2\sigma_r \leq \frac{\lambda}{2}$

I.e. the dual mean square error of the determination of a difference in the distances in this case will not exceed the widths of phase path/track on the base of ground stations, which with probability into 95o/o provides uniqueness in the determination of the line of

position.

During creation and use of differential ranging systems of long-range, which work on long waves, very complex and difficult problem is the fight with the errors, caused by the effect of the sky waves which come into the otchku of reception after reflection from the ionosphere (Fig. 3.25).

The length passable by them path as a result of the vertical displacement of reflecting layers continuously changes, which leads to changes in the phase of the taken signals.

Fig. 3.25. Propagation of surface and three-dimensional/space radio waves.

Key: (1) the ionosphere. (2) sky wave. (3) ground wave. (4) the point of reception. (5) the surface of earth.

Page 158.

At the point of reception occurs the addition of the fields of surface and sky waves and is formed the resulting signal whose phase differs from the phase of the basic signal by certain value $\Delta\phi$ (Fig. 3.26). The phase of sky wave φ_{np} is random variable; therefore value $\Delta\phi$ is also random and varies within the limits $\pm\Delta\varphi_{макс}$ depending on amplitude ratio $\frac{E_{np}}{E_{noв}}$

(3.62) $$\Delta\varphi_{макс} = \operatorname{arctg}\frac{E_{np}}{E_{noв}}.$$

The root mean square value of this deflection is approximately equal

(3.63). $$\sigma_{\varphi}^{\circ} = 40\frac{E_{np}}{E_{noв}}.$$

In order that the accuracy of phase measurements under these conditions would be not below 1/100 phase cycles, the strength of the field of ground wave must exceed not less than 10 times the strength of the field of sky wave.

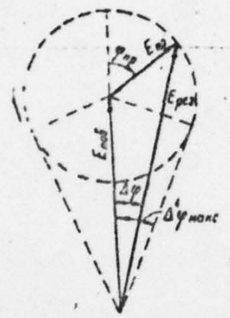
During the propagation of long waves up to distances more than 700-800 km the field of sky wave begins to exceed on intensity/strength the field of ground waves and measurement of their phase during continuous emission/radiation they become impossible.

For providing an accuracy of phase measurements at large

distances in radio-navigation systems they began to apply the pulsed operation of emission/radiation, which makes it possible to divide the reception of surface and sky waves in terms of time. Sky wave with respect to surface passes larger distance and therefore it delays on time. A difference in the passable distances depends on the superstandard range and time of days, since the in the daytime long waves are reflected from layer $\mathcal{A}$ in height/altitude of approximately 70 km, but at night - of more highly lying/horizontal layer E in altitude 100-110 km.

The value of the time lag prostransvennykh waves at frequency f = 100 kHz is shown in Fig. 3.27. From the given curve/graphs it is evident that a delay in the sky wave, being gradually decreased with an increase of distance, approaches value τ_3 = 40-50 μs. If we emit momentum/impulse/pulses by dlitel'nsot'yu τ order 50 μs, as this is made in system loran-A, then into the point of reception surface and three-dimensional/space will come separate. However, when using long waves in technical reasons it is necessary to work by longer momentum/impulse/pulses by duration on the order of 200 μs and more; therefore the cover plates of surface and three-dimensional/space signals become unavoidable.

Fig. 3.26. Addition of surface and sky waves at the point of reception.



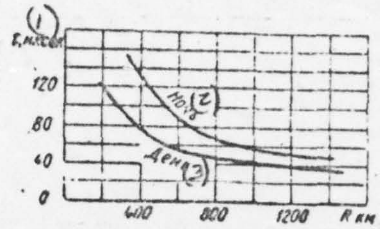
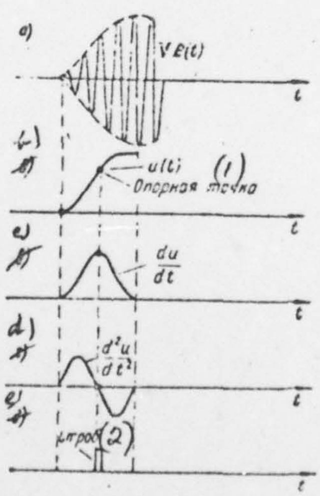


Fig. 3.27. Time lag of sky wave.

Key: (1) µs. (2) night. (3) day.

Fig. 3.28. Reception and processing pulse signals in fazo-time/temporary systems.

Key: (1) data points. (2) gate/strobe.



For the target/purpose of the separation of signals with reception for measurements are utilized the only part of the momentum/impulse/pulse, its leading edge, which they try to make abrupt/steepest (Fig. 3.28a). Going around this part of the taken momentum/impulse/pulse u (t) (Fig. 3.28b) they differentiate, obtain derived du/dt (Fig. 3.28c) whose maximum will coincide with the point of the greatest slope/transconductance of the leading edge of the taken momentum/impulse/pulse u (t). After the second differentiation they obtain d^2u/dt^2 (Fig. 3.28d) and transition point of its through zero is utilized for the formation of the gate/strobe (Fig. 3.28e), shifted relative to the beginning of momentum/impulse/pulse on 30-40 µs, i.e., for a period knowingly lesser than a delay in the sky wave. These operations are carried out with the signals of the leading and slave stations, obtain two gate/strobe, strictly attached on time to the taken momentum/impulse/pulses from ground stations and is conductn the measurement of a time difference of their reception $t_{\text{н}}$. These measurements make it possible to unambiguously determine the number of phase path/track. Then is utilized high-frequency filling of the taken momentum/impulse/pulses on the chosen section of their leading edge, not affected by sky wave, are conductr phase measurements, is determined the phase difference of the taken signals for obtaining line of position with high accuracy. Thus it is possible to get rid of the mixing effect of sky waves.

Page 160.

In the contemporary reception indicator devices of fazo-time/temporary type systems, for example Loran-S, the processes of the search for received signals, measurement of their temporary situation relative to each other and the measurement of a phase difference full-automatic.

The results of the obtained measurements are introduced into the computers with the aid of which are calculated the geographical reference of aircraft, bearings and distances of the assigned reference points and the other data, necessary for the navigation of flight vehicles.

Weight of installed equipment of fazo-time/temporary systems in contemporary performance of approximately 40 kg.

Page 161.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FTD-ID(RS)T-0659-76	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) RADIO EQUIPMENT FOR AIR NAVIGATION		5. TYPE OF REPORT & PERIOD COVERED Translation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G. P. Astaf'yev, V. V. Grachev, A. S. Kul'chiy		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Force		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1972
		13. NUMBER OF PAGES 353
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

17; 01

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)